IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

SPRINT COMMUNICATIONS COMPANY LP., *Plaintiff*, v. CHARTER COMMUNICATIONS, INC., *et al.*, *Defendants*.	C.A. No. 17-1734-RGA **PUBLIC VERSION**
SPRINT COMMUNICATIONS COMPANY LP., *Plaintiff*, v. MEDIACOM COMMUNICATIONS CORP., *Defendants*.	C.A. No. 17-1736-RGA **PUBLIC VERSION**
SPRINT COMMUNICATIONS COMPANY LP., *Plaintiff*, v. WIDEOPENWEST, INC. *et al.*, *Defendants*.	C.A. No. 18-361-RGA **PUBLIC VERSION**
SPRINT COMMUNICATIONS COMPANY LP., *Plaintiff*, v. ATLANTIC BROADBAND FINANCE, LLC *et al.*, *Defendants*.	C.A. No. 18-362-RGA **PUBLIC VERSION**
SPRINT COMMUNICATIONS COMPANY LP., *Plaintiff*, v. GRANDE COMMUNICATIONS NETWORKS, LLC *et al.*, *Defendants*.	C.A. No. 18-363-RGA **PUBLIC VERSION**

EXHIBITS 49-87 TO THE DECLARATION OF KELLY E. FARNAN IN SUPPORT OF CHARTER'S AND DEFENDANTS' OPPOSITION TO SPRINT'S MOTIONS FOR SUMMARY JUDGMENT AND MOTIONS TO EXCLUDE EXPERT TESTIMONY UNDER *DAUBERT*

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EXHIBITS 49 - 72

REDACTED IN THEIR ENTIRETY

EXHIBIT 73

Value Shares of Technologically Complex Products

Jonathan D. Putnam[1, 2]

April 16, 2014

[1]Competition Dynamics. Earlier drafts benefited from discussions with Peter Boberg, Peter Schwechheimer and Andrew Tepperman, but I alone am responsible for any errors. I received valuable research assistance from Matt Johnson.

[2]The ideas presented in this paper reflect some of the factors that may contribute to a complete patent damages analysis. Nothing in this paper should be construed as a complete damages analysis, which in general depends on additional facts that are specific to any given case.

subdivided, or when the sources of aggregate profit must be allocated among individual causes. Alternatively, there are various reasons to extrapolate from a known part to some larger, but unobservable, whole.[18]

In litigation—which focuses almost entirely on the asserted patent, with little or no mention of others in the portfolio—patentees routinely claim that v_n is "large," while accused infringers claim that it is "small." Through some combination of (1)–(4), these claims can often be expressed in terms of P, V, $\overline{v}$ (or their royalty, asset and profit analogues, as applicable) and s_n, and tested for their internal consistency and/or consistency with other data. It will be convenient to assume that P, V and $\overline{v}$ and/or their analogues are observable or otherwise not disputed. This assumption allows us to focus on the determination of s_n—*i.e.,* on apportionment. Section 4 provides values of K_n, M_n and ΔL_l^u that make these determinations easy to implement from the empirical literature.

3 Empirical Literature

Beginning with Pakes and Schankerman (1984), economists have employed a variety of methods to derive the distribution of patent values from optimizing behavior. Broadly speaking, these efforts can be divided into two types: "longitudinal" models of patent renewal decisions, and "cross-sectional" models of patent family (country choice) decisions. Each of these types can be further divided into "perfect foresight" models, which assume that initial returns decay at a deterministic rate, and "option" models, which permit returns to evolve stochastically. Analysts typical assume that initial returns are distributed log-normally.[19]

Papers based on patent renewal methods generally provide estimates for individual European countries, because there are too few renewal decisions during the life of a US patent to identify the distribution. Lanjouw et al. (1998) surveys most of the relevant research. Since then,

[18] For example, Teece (2000, p. 207) describes a procedure by which prospective cross-licensees each create a list of their top patents (a "proud list"), and rate them in various dimensions: likelihood of infringement, validity and next-best alternatives. Each patent receives an aggregate score, which is then multiplied by a common royalty rate. The sum of these weighted royalties constitutes each firm's aggregate claim on the other. According to Teece, the complete analysis of a pre-2000 complex semiconductor device could require 400-500 hours.

[19] The log-normal distribution can be justified theoretically by modeling technical change as the product of independent multiplicative improvements to a production function, and appealing to a central limit theorem. Schankerman and Pakes (1986) reported that the log-normal distribution fit best among the several distributions they tested.

Bessen (2008) estimates a deterministic model based on US patent renewals, using observed patent covariates (such as subsequent citations in later patents) to identify the value distribution. Among papers analyzing the choice of international patent family, Deng (2011) has integrated the various strands of the literature into a single general model of (European) patent family and renewal decisions with stochastic returns. Chan (2010) estimates an international patent family application model using firm-level data for the agricultural biotechnology sector.

All of these models are identified, partially or completely, using the behavioral assumption that each year a patentee compares the annual return to patent protection, r_t, to the annual cost of maintaining that protection, c_t, and responds optimally by either renewing the patent, or not. In each model, the distribution estimated is that of the initial annual return, r_1 (which captures the first-year return received by the inventor).[20] Patent family models assume, in addition, that in each country j in which an application is observed the capitalized asset value (over the life of the patent) exceeds the initial application cost: $v_j = \sum_{t=1}^{T^*} \beta^t (r_{jt} - c_{jt}) > C_{j0}$, where C_{j0} is the cost of filing in country j, $T_j^* \leq \overline{T}_j$ is the length of the patent's life (assuming optimal renewal decisions, subject to the statutory maximum life $\overline{T}_j$), $0 < \beta < 1$ is a discount factor, and r_{j1} depends in addition on an invention-specific random effect that is common across countries.

For present purposes, the salient conclusions of these papers are:

1. The assumption that r_1 is distributed log-normally fits the data well (and better than other parametric distributions).

2. Though the studies naturally reach different conclusions on the mean value of patent rights,[21] (which varies with the log-normal location parameter μ_{r_1}) the scale parameter σ_{r_1} falls within a relatively narrow range (typically about $1.5 - 2.2$).

To facilitate the exposition, I assume log-normality of the value distribution (*i.e.*, that $\ln v \sim N(\mu_v, \sigma_v)$),[22] but as Section 4.3 shows, this assumption is not essential to the main results

[20] In "deterministic" models, r_t is typically modeled as $r_t = r_1 \delta^{t-1}$, where $\ln r_1 \sim N(\mu_{r_1}, \sigma_{r_1})$ and $0 < \delta < 1$ is a depreciation factor. In "stochastic" models, r_t evolves according to a stochastic process which permits the value of the patent to increase, though with decreasing probability, over time. The two methods generally imply similar valuations in the right tail of the distribution, *i.e.,* among high-value patents.

[21] For example, patents are worth less in smaller countries, and values vary systematically by technology field.

[22] The distribution of v is approximately, but not exactly, log-normal, because (*a*) v is the sum of log-normals,

of the paper.

Almost all of the studies report v for the samples they examine at standard percentiles (generally at least 0.25, 0.50, 0.75, 0.90, 0.95 and 0.99). From the reported values, it is simple to compute the implied distribution of v over the range between two percentiles, assuming log-normality. Let v_u be the value of v reported for the upper percentile, and v_l be the value reported for the lower percentile. Then we have $v_u = \exp[\mu_v + \sigma_v F^{-1}(u)]$ and $v_l = \exp[\mu_v + \sigma_v F^{-1}(l)]$, where $F(\cdot)$ is the standard normal distribution function. Solving these equations jointly for μ_v and σ_v gives:

$$\sigma_v = (\ln v_u - \ln v_l)/[F^{-1}(u) - F^{-1}(l)] \tag{11}$$

Table 1 reports the values of σ_v inferred using (11) from the estimates reported in various studies. These studies examine the patent value distribution across a range of countries, technologies and time periods, using both patent renewal and patent family application methods. With the exception of Bessen (2008) and Chan (2010), all of them report the simulated distribution of patent values at the same percentiles.[23]

Table 1: Value of σ_v implied from various patent renewal and patent application studies

Estimates of σ_v vary somewhat over the different intervals between percentiles. In general, the implied value of σ_v decreases in the right tail of the distribution, partly because truncation has less effect on the values there.

The table highlights several differences among the studies, and hints at possible explanations for those differences. For example, unlike other studies, Lanjouw (1998) assumes an exponential

which is not log-normal; (*b*) the application fee C_0 and annual renewal fees c_t cause inventors who draw a low value for r_1 either not to file at all, or to allow their patents to lapse prior to reaching $\overline{T}$; both of these distortions truncate the left tail of the distribution of v; and (*c*) these fees constitute a larger proportion of lower-value patents, further skewing the v distribution (which, unlike the distribution of r_1, is based on value net of fees). For these reasons, the implied values of σ_v vary somewhat over the support of v. Note that any sample drawn from the log-normal distribution satisfies assumptions (1)–(4), and is therefore AUC-consistent, provided that the draws are independent.

[23]The value reproduced from Bessen (2008) is the middle of three estimates reported for σ_{r_1}, which generally falls near the middle of the implied range for σ_v. Chan (2010) reports percentiles corresponding to points in the support of the distribution that are fixed across the countries she studies. I calculate σ_v for the percentiles that most nearly match those shown in Table 1.

distribution of initial returns, which (having a thinner right tail) appears to yield lower estimates of σ_v than are found by authors who assume a log-normal distribution. In general, the international patent family studies find higher estimates for σ_v than those found in studies based on patent renewal data.[24] On the other hand, there appears to be no systematic difference between studies that assume perfect foresight and those that allow for the stochastic evolution of returns.

For present purposes, the main conclusion from Table 1 is that the values of σ_v fall within a relatively narrow range.[25] The median value of σ_v ranges from about 2.1 for the bottom 75% of the distribution to about 1.7 for the top 5%.

It is important to study the impact of variations in σ_v on the value distribution, to understand the circumstances in which such variation does and does not matter for the apportionment of value. Figure 1 plots Lorenz graphs (from (6)) for values of σ_v ranging from 0 to 3. A value of 0 implies that all patents have the same value (the "45 degree line"). As σ_v increases, the distribution becomes increasingly skewed, with the right tail of the distribution commanding an increasing fraction of the total value. For example, for $\sigma_v = 1$, the bottom 90% of the distribution represents about 61% of the total value ($L_{90} = 0.68$), which implies that the top 10% of patents constitute 39% of the total ($M_{90} = 3.9$). For $\sigma_v = 2$, the figures are: $L_{90} = 0.24$, $M_{90} = 7.6$.

Figure 1: Lorenz graphs of the patent value distribution for selected σ_v

The heavy line in Figure 1 plots the composite Lorenz graph constructed using the medians of the estimates reported in Table 1. The median graph lies between those plotted for $\sigma_v = 1.5$ and $\sigma_v = 2$.

Though the aggregate skewness of the distribution varies markedly, depending on σ_v, the next section shows that the shares of the distribution are quite stable over the vast majority of the

[24] Chan (2010), a study of agricultural biotechnology inventions that were made by commercially successful firms, consistently shows the highest estimates across all studies. Such patents may exhibit greater skew.

[25] Relatively small variations in σ_v, by themselves, imply relatively large variations in the expected value of the underlying distribution, which is given by $E[v] = \exp(\mu_v + \sigma_v^2/2)$. But we are interested in the *shares* of the distribution, and take the expected value as having been estimated from other data (such as average profit per patent). Variations in σ_v are relevant only insofar as they affect the implied shares. As I explain, shares do not vary much with σ_v, except in the extreme right tail.

Figure 1
Lorenz graphs of the patent value distribution, for selected σ_v

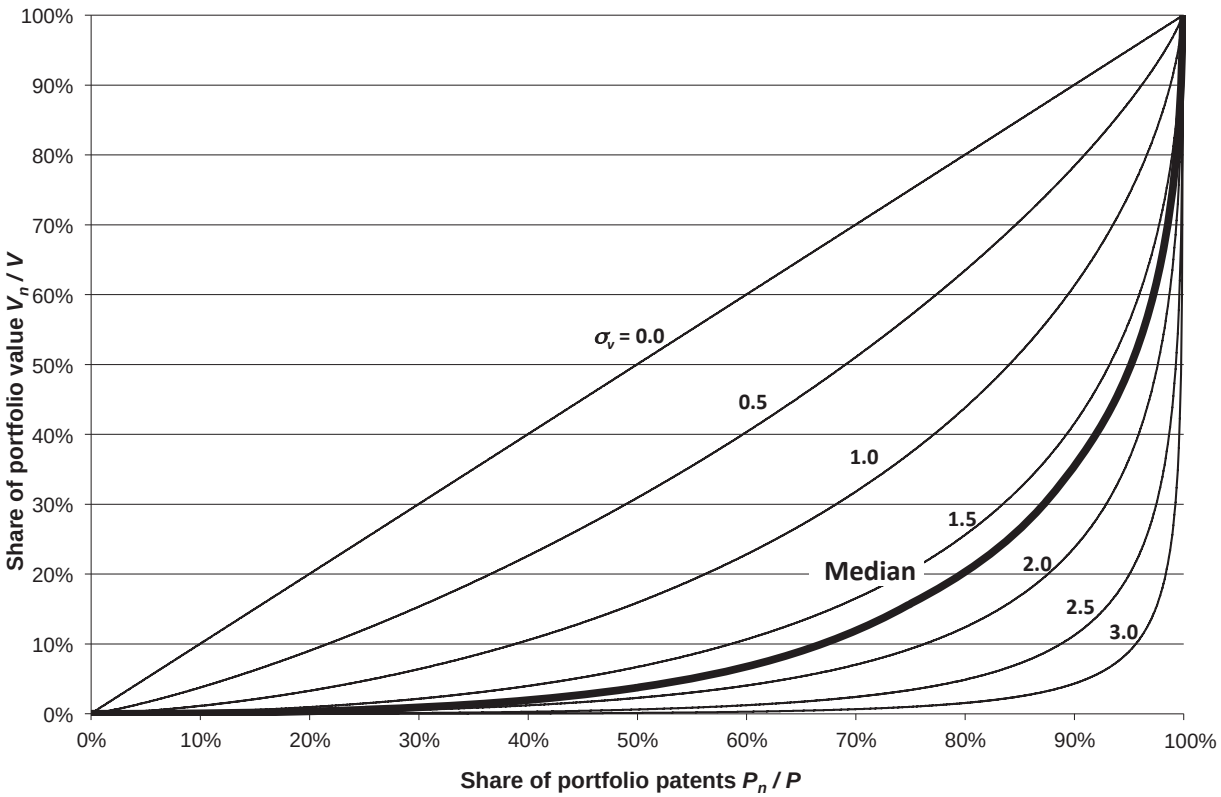

EXHIBIT 74

How Valuable is Patent Protection? Estimates by Technology Field

Mark Schankerman

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How valuable is patent protection? Estimates by technology field

Mark Schankerman*

I present evidence on the private value of patent rights in France for different technology fields and nationalities of ownership, using nonparametric techniques and a parametric model of patent renewal. The distribution of the value of patent rights is highly skewed, patent protection is a significant but not the major source of private returns to R&D, and these characteristics vary across technology fields. I compute the R&D cash subsidy that is equivalent to the value of patent rights, measure the variations in value over time, technology fields, and nationalities, and show that these differences are correlated with patent grant rates.

1. Introduction

■ This article provides evidence on the importance of the patent system as a source of economic returns to R&D. Firms can and do use various methods to protect their inventions, including patents, secrecy, licensing agreements, and different forms of first-mover advantage (see Levin et al. (1987); Cohen, Nelson, and Walsh (1996)). The decision to patent an invention rests on the relative costs and benefits of these alternative methods. The private value of patent rights represents the *incremental* returns generated by holding a patent on the invention, above and beyond the returns that could be earned by using the second-best means. One would expect the value of patent protection to vary across inventions because of differences both in the underlying private value of the inventions and in the relative effectiveness of patents in protecting them. To formulate good public policy on intellectual property rights, it is important to know whether patent protection is effective in providing incentives to do R&D, whether its importance varies significantly across broadly defined technology fields, and how other government policies—such as restrictions on patent licensing, R&D cooperation, and price regulation—may affect the effectiveness of patent protection.

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An earlier version of this article was presented at a conference in honor of Zvi Griliches at the Hebrew University of Jerusalem. I am extremely grateful to two referees for providing very detailed and constructive suggestions that greatly improved the article in many ways. I also thank them and the Editor for their patience during a long revision process. Finally, I am grateful to Jean Lanjouw for many useful suggestions, Margaret Simpson for providing the computer code for the nonparametric tests, Jonathan Putnam for providing the patent concordance used in the Appendix, and Alison Hole for research assistance on the nonparametrics. Any remaining errors and interpretations of the findings are my responsibility. The research was financed by the National Science Foundation, grant no. SRS-8517742, with additional support from the Centre for Economic Performance at the London School of Economics.

There are no well-developed markets in patents where we can directly value patent rights. Therefore, most of the available evidence on the importance of patent protection comes from survey data (Taylor and Silberston, 1973; Mansfield, Schwartz, and Wagner, 1981; Levin et al., 1987; Cohen, Nelson, and Walsh, 1996). This literature points to two main conclusions: first, that patents are not the exclusive, or even the primary, device for protecting inventions in most industries, and second, that some industries (especially pharmaceuticals) rely much more heavily on patents than others. Recent work on models utilizing patent-renewal data has shown that they can be used to derive quantitative estimates of the private value of patent protection. Most countries require payment of annual renewal fees to maintain patent protection on inventions, until the statutory limit (typically 15–20 years) is reached. Under the assumption that patentees make a profit-maximizing renewal decision, data on patent renewal rates and fees can be used to infer the private value of patent protection. Pakes and Schankerman (1984) developed the original deterministic model to use patent-renewal data in this way. Versions of this model have been applied to aggregate data by Schankerman and Pakes (1986) and Sullivan (1994). Since then there have been two classes of patent-renewal models developed, parametric models that allow for uncertainty (Pakes, 1986; Lanjouw, forthcoming) and nonparametric methods that also allow for uncertainty but provide less detailed information than parametric models (Pakes and Simpson, 1989). Finally, in important related work, Putnam (1996) develops and estimates models of the decision to apply for a patent on an invention in multiple countries, and shows that such patent-family data can yield detailed information about the private value of international patent rights. In principle it should be possible, and very illuminating, to combine patent-family and patent-renewal data, but this remains to be done.

The objective of this article is to extend the research on patent renewals by investigating the private value of patent rights in France in four technology fields: pharmaceuticals, chemicals, mechanical, and electronics. In addition, I use the techniques developed by Pakes and Simpson (1989) to present nonparametric evidence on differences in patent-renewal patterns across these four technology fields and five nationalities of ownership: France, Germany, United States, United Kingdom, and Japan. The empirical analysis is based on a new dataset covering nearly all patents applied for in France during the period 1969–1982.

This article, and patent-renewal data generally, provides information only about the *private value* of patent rights, since the renewal decision is presumably not affected by social returns that the firm cannot appropriate. This information is an important ingredient in assessing the economic effects of the patent system, but it needs to be supplemented by information on the social returns from patent activity. Recent studies have shown that patent-citations data can be useful in tracing the spillovers and social returns from patented inventions (Trajtenberg, 1990; Jaffe, Trajtenberg, and Henderson, 1993). Thus patent-renewal and patent-citations data should be viewed as complementary sources of information on the returns to R&D. One further consideration should be kept in mind in interpreting empirical findings derived from patent-renewal data. There is an important distinction between the private value of the patent system as measured *before* the decision to patent an invention and *after* such a patent has been taken out. As Horstmann, MacDonald, and Slivinski (1985) emphasize, the patent application itself reveals private information about the invention, and it may be very difficult to appropriate rents without patent protection once this information is revealed. Thus there will be greater willingness to pay for patent protection after disclosure than before the decision to patent is taken. This article estimates the *ex post* value of patent rights and on this account should be interpreted as an upper bound to the *ex ante* value. But there is a countervailing consideration. Judd (1989) has pointed out that the patent system may generate private returns by discouraging competition at the invention stage

merely by offering the possibility of a patent, even if no patent is actually taken out by the winner. Therefore, patent-renewal data may not fully capture the private gains due to strategic responses and, on this account, will underestimate the *ex ante* private value of the patent system.

Patent-renewal data are potentially important as a research resource because they can be used to learn about how the value of patent rights varies across various dimensions, including (but not limited to) technology fields, nationalities of ownership, and time. But the effectiveness of patent protection should be expected to depend on other features of the institutional environment in which firms operate, in particular those aspects of regulation and competition policy that constrain the ability of patentees to appropriate the social surplus from their inventions. A number of recent studies have shown how R&D cooperation, patent licensing, and patent length and breadth interact in determining R&D incentives (Gallini and Trebilcock, 1995; Green and Scotchmer, 1995; Scotchmer, 1996). This article studies patent protection in France and reflects the institutional arrangements there. This turns out to be empirically important, since one of the sectors studied (pharmaceuticals) was subject to strict price regulation and this heavily influences the value of holding patents in that sector. This finding, which I shall discuss at some length, underscores the importance of how different public policies interact in determining R&D incentives. And it points to the need for a comparative study of renewal data from patent systems in different countries, broken down by technology field, ownership nationality, and possibly other dimensions. It is only in this way that we will be able to identify and assess the importance of institutional factors on the effectiveness of patent protection, and R&D incentives more generally.

My main empirical findings can be summarized as follows. The distribution of the private value of patent rights is sharply skewed in all technology fields, with most of the value concentrated in a relatively small number of patents in the tail of the distribution. However, there are sharp differences across technology groups, which fall rather neatly into two categories. The first group comprises pharmaceuticals and chemicals, with value distributions that are characterized by relatively low mean and dispersion, and slow rates of depreciation. The second group consists of mechanical and electronic patents, with value distributions characterized by a higher mean value, greater dispersion, and faster depreciation. I also find clear evidence of a sharp jump in the depreciation rates for 1974 and 1980, which I associate with the oil price shocks during those years. The estimates imply that the price shocks reduced the value of patent rights for the existing stock of patents in each of the four technology fields by about 24% in 1974 and 18% in 1980. This is quite similar to the decline in Tobin's q for the manufacturing sector observed in leading OECD countries (Chan-Lee, 1986).

The evidence shows that the patent system confers valuable property rights. Averaged over technology fields, the private value of these property rights is equivalent to an R&D cash subsidy rate of about 15–25%, depending on whether one includes only private or also government-financed R&D in the computation. Thus it is clear that patent protection provides a substantial incentive to R&D effort, but it does not appear to be the major source of private returns to inventive activity. This confirms survey evidence that firms rely on a variety of mechanisms other than patents to protect inventions. But I also find that the importance of patent protection varies sharply across technology fields in France, being roughly equivalent to an R&D subsidy of 5–10% for pharmaceutical and chemical patents and 15–35% for mechanical and electronics patents. I shall argue that the surprising unimportance of patent protection in pharmaceuticals is caused by the fact that there was very stringent pharmaceutical price regulation in France. Thus this finding may not apply in other countries where such regulation is less severe or absent.

The mean value of patent rights differs across nationalities of ownership, and these differences are quite stable over the sample period. Japan and France have the largest mean value in each technology field, followed by the United States, Germany, and the United Kingdom. Patents originating in Japan are substantially more valuable than in other countries, and the difference is most striking for electronics patents. I cannot determine with the available data how much of these cross-country differences in mean value are due to the self-selection that occurs in the patent application process rather than differences in the underlying quality of the inventions. But I do find strong positive correlation between the estimated mean value of patent rights and the patent grant rates for different nationalities, and this holds in all four technology fields. This result suggests that it may be possible to use such cross-sectional variation in grant rates as an indirect indicator of the "quality" of patents originating from different countries.

The article is organized as follows. Section 2 describes the data and provides nonparametric evidence of technology field and nationality differences in patent-renewal patterns, using equality and stochastic dominance tests. The patent-renewal model is summarized in Section 3. Section 4 presents the parametric estimates and their implications for the four technology fields (pooling nationalities). Section 5 presents the simulated distributions of the value of patent rights. Section 6 provides estimates of the equivalent cash subsidy to R&D due to patent protection. The empirical estimates of the model when both nationality and technology field differences are incorporated are provided in Section 7. I also discuss the differences in mean value across nationalities and over time, and the empirical relationship between changes in mean value and patent grant rates. Concluding remarks highlight key findings and directions for further research.

2. Data and nonparametric tests

■ The dataset was constructed from computerized files of individual patents from the French patent office (see Schankerman (1990) for details). The data cover all patent applications in France for the period 1969–1982 and patent renewals for 1970–1987, broken down by patent application date (cohort), technology field, and nationality of the owner (normally the inventor). For each cohort/technology field/nationality cell, the data include the number of patent applications, the number of patent grants during each of the years subsequent to cohort date, and the number of patent renewals at each available age. Every patent is assigned by an examiner to a primary technology field according to the International Patent Classification (IPC). Assignment is based on the function of the invention (e.g., conveyer belts are classified as industrial transport apparatus), which may differ both from industry-of-origin and industry-of-use criteria. The data are broken down into fourteen technology groups (corresponding to IPC subsections) that account for over 90% of patent applications in France.[1] For most of the analysis, I consolidate them into four major groups based on fundamentally different types of technologies: pharmaceuticals, chemicals, mechanical, and electronics (see Schankerman, 1990). This article uses patent applications in France for five nationalities: France, Germany, the United Kingdom, Japan, and the United States. Renewal fees were obtained directly from the French patent office. Renewal fee schedules were changed frequently during the sample period, but the prevailing schedule applied to all patents regardless of cohort, technology field, or nationality. Renewal fees start at very

[1] Due to constraints in the original project design, certain groups of IPC classes were not included in the dataset. The main omitted categories are nuclear energy, armaments, agriculture, foodstuffs and tobacco, personal and domestic articles, and printing (for details, see Schankerman (1990)).

TABLE 5 Distribution of the Value of Patent Rights, by Technology Field: 1970 Cohort

Quantile	Pharmaceuticals	Chemicals	Mechanical	Electronics	Electronics (excluding Japan)
.25	515	447	638	1,450	627
	(128)	(103)	(312)	(1,256)	(279)
.50	1,631	1,594	2,930	7,933	3,159
	(539)	(591)	(1,666)	(9,228)	(1,708)
.75	5,427	5,807	13,769	46,964	16,322
	(2,437)	(2,859)	(9,935)	(53,265)	(11,055)
.90	11,787	13,735	40,840	170,958	53,122
	(6,061)	(7,039)	(35,547)	(315,079)	(58,822)
.95	19,920	24,363	83,857	402,292	113,403
	(11,211)	(13,814)	(81,228)	(826,778)	(105,162)
.99	52,139	69,906	321,966	2,016,797	481,429
	(34,565)	(46,983)	(375,386)	(4,984,719)	(538,827)
Mean	4,313	4,969	15,120	68,502	19,837
	(1,995)	(2,591)	(13,692)	(134,208)	(18,020)

Notes: Figures refer to the private value of patent rights (in 1980 U.S. dollars), measured from date of patent application. They are simulated using parameter estimates for the log-normal patent-renewal model with fixed cohort effects in μ and year effects in δ, columns (3) in Table 4. The discount rate is set at .10. Estimated standard errors in parentheses are computed by the delta model.

of the total value in each technology group. The top 1% of patents accounts for 12% and 14% of the total value of patent rights in pharmaceuticals and chemicals, respectively, and 21% and 24% for mechanical and electronics patents (excluding Japan). The top 5% of patents accounts for 34% and 38% of total value in pharmaceuticals and chemicals, and 50% and 55% for mechanical and electronics patents.[12] The quantiles are estimated quite precisely in pharmaceuticals and chemicals but less so in the mechanical and electronic technology fields, especially in the upper 5% of the tail. Still, the mean value differs sharply across technology fields: $4,313 in pharmaceuticals, $4,969 in chemicals, $15,120 for mechanical patents, and $19,837 in electronics (excluding Japan). Table 5 confirms that the technology fields break down into two distinct categories in terms of the mean value and dispersion in the distributions.[13] It is interesting to note that including Japanese electronics patents raises the mean value by a factor of three and greatly reduces precision.

[12] The fraction of total value in the top percentile is given by $.01\ V_{99}/V_m$, where V_{99} is the value for the top percentile and V_m is the mean value. This is a conservative estimate, since it assigns the lower bound values V_{99} to all patents in the top percentile. For the top 5% of patents, the figure is computed as $.025V_{95} + .015V_{975} + .01V_{99}$. Inclusion of Japan in electronics raises the figure by about five percentage points. The estimates are almost identical using the model without oil shocks.

[13] As noted in Section 2, the grant rate is much larger in pharmaceuticals and chemicals than in the other technology fields, for each nationality. One hypothesis is that inventions in these areas are more "patentable" under existing patent law. An alternative is that patent examiners screen patents according to some fixed cutoff (defined in terms of "inventive step") that is correlated with patent value, and that the distributions of patent values in pharmaceuticals and chemicals stochastically dominate those in the other fields. But the estimated mean values are not consistent with stochastic dominance (see also footnote 10), and thus favor the first hypothesis.

EXHIBIT 75

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A STUDY OF PATENT MORTALITY RATES: USING STATISTICAL SURVIVAL ANALYSIS TO RATE AND VALUE PATENT ASSETS

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rates of return, and related considerations.[24] Thus, for example, a rational economic decision maker should choose to make additional incremental investments in a patent asset (i.e., payment of maintenance fees) only if he or she believes that the patent will produce expected future economic benefits sufficient to justify the further investment.

Of course, not all relevant decision makers will behave rationally and economically in all cases. Individual decision makers may choose to invest uneconomically in patents or other intellectual property assets for a variety of reasons, for example, to achieve personal recognition or to superficially "dress up" balance sheets to attract potential investors or buyers. A variety of individual psychological factors can also influence investment decisions, sometimes producing irrational or non-economical results. Thus, for example, the so-called "lottery effect" may encourage some to over-invest in highly speculative technologies that have the seductive allure of potentially huge economic rewards, but very little, if any, realistic probability of success. Others may fail to take full advantage of lucrative patent investment opportunities because of fundamental misunderstandings or misinformation concerning the effective use and exploitation of patents. The statistical model assumes any such irrationalities or other perturbations follow a normal distribution and, therefore, "average out" in a sufficiently large sample population.

ASSUMPTION 2: Patent values are lognormally distributed.

Like stocks, bonds, and other intangible assets, patents possess no inherent or intrinsic value. They are valued based on what they can produce or provide to the holder of the asset in terms of a future return on

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[24] *See, e.g.*, H. CRAIG PETERSON & W. CRIS LEWIS, MANAGERIAL ECONOMICS 9, 511-12 (4th ed. 1999).

investment.[25] If returns are normally distributed, the underlying value of a randomly selected sample of such assets should follow a lognormal probability distribution. This conforms with standard statistical modeling of expected price distributions of primary financial instruments.[26]

Based on these assumptions and the reported maintenance data, a statistical relationship can be formulated between observed patent maintenance rates and the probable distribution of patent values implied by those observations.[27] In particular, we can derive a value distribution curve, illustrated in Figure 2,[28] that roughly approximates the probability distribution of expected patent values for a random sample of patents issued in 1986.

Figure 2 is developed from reported PTO maintenance data for a sample population of approximately 70,000 patents issued in 1986. Data points were calculated representing threshold or minimum cut-off values for each of three sub-populations consisting of patents maintained through the fourth, eighth, and twelfth years, respectively. Cut-off values were calculated as a simple sum of fixed annual net revenues taken over the life of the patent. Net annual revenues were calculated according to the minimum amount required to economically justify payment of the last-paid

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25 *See* SMITH & PARR, *supra* note 2, at 15.

26 *See* SIMON BENNINGA, FINANCIAL MODELING (2d ed. 2000).

27 *See* Ariel Pakes & Mark Schankerman, *The Rate of Obsolescence of Patents, Research Gestation Lags, and the Private Rate of Return to Research Resources*, *in* R&D, PATENTS, AND PRODUCTIVITY (Zvi Griliches ed., 1984); ZVI GRILICHES, PATENT STATISTICS AS ECONOMIC INDICATORS: A SURVEY PART I (Nat'l Bureau of Econ. Res., Working Paper No. 3301, 1990), *available at* http://www.nber.org/ papers/w3301; Jean O. Lanjouw et al., *How to Count Patents and Value Intellectual Property: The Uses of Patent Renewal and Application Data*, 46 THE J. OF INDUS. ECON. 405 (1998).

28 *Infra* p. 339.

maintenance fee given the remaining life of the patent. For example, a patent owner considering whether to pay the third maintenance fee (blended, adjusted rate of $2,962) to maintain a patent beyond the twelfth year would need fixed annual net revenues of $592 ($2,962 divided by five years of patent life remaining) to break even on the investment. Multiplying this amount by seventeen years (full patent term in 1986) yields an implied minimum cut-off value of roughly $10,070. A lognormal probability distribution curve was then fitted to the calculated data.

According to the model, the bottom 10% of patents (the tenth percentile and below) in the sample population had an implied value at issuance equal to or less than about $430.[29] The top 10% of patents (ninetieth percentile and above) had an implied value greater than about $112,500. The fitted lognormal curve correlates to an expected median value of $6,930 and a mean value of $73,340.[30] Table 1[31] is a summary of patent values and percentage contributions to total value by percentile, according to the model.

The aggregate implied value of all 70,860 patents issued in 1986 was about $5.2 billion ($3.2 billion in 1986 dollars) according to the model, with about 780 patents valued in excess of $1 million accounting for about 55%

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[29] All reported dollar amounts are in 2001 inflation-adjusted dollars unless otherwise indicated.

[30] These values are significantly *lower* than those suggested by other studies. *See, e.g.*, Neifeld, *supra* note 14, at 212-13 (suggesting a mean valuation of about $2.1 to $2.5 million for patents issued from 1990 to 1993). Such high valuations seem implausible, however. A patent is not unlike an expensive lottery ticket; you pay your money up front and hope for the big payoff. If the *average* payoff were really millions of dollars, one would expect more demand for patent "lottery tickets" and commensurately higher costs to obtain them. Mean valuations in the range estimated by the statistical model seem intuitively more plausible given currently prevailing costs for obtaining patents.

[31] *Infra* p. 349.

of this amount. Figure 3[32] illustrates an estimated probability distribution of expected patent values (x-axis, logarithmic scale) and corresponding percentage contributions to total aggregate patent value (y-axis) according to the statistical model.

Figure 3 illustrates that patents having estimated values between about $580 thousand and $2.4 million (represented by the middle two bars, averaging $1.1 million) account for approximately 25% of the total aggregate implied value of the sample population. Patents having estimated values less than about $25,000 (about 72% of the sample population) account for only about 6% of the total aggregate value according to the model. Thus, the model supports the view, long held by many in the field, that patent values are highly skewed.[33] A relatively large number of patents appear to be worth little or nothing while a relatively small number appear to be worth a great deal.

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[32] *Infra* p. 340.

[33] *See, e.g.*, HALL, *supra* note 13, at 14.

Table 1. Implied Patent Value and Percentage Contributions to Total Value by Percentile (1986)[62]

Percentile	Implied Value	% Total Value
1.000%	$45	0.01%
5.000%	$195	0.02%
10.000%	$430	0.19%
25.000%	$1,606	1.28%
50.000%	$6,960	5.21%
75.000%	$30,000	12.0%
90.000%	$112,500	11.2%
95.000%	$247,500	26.3%
99.000%	$1,090,000	25.9%
99.900%	$5,700,000	11.8%
99.990%	$22,400,000	4.3%
99.999%	$73,300,000	1.8%

Table 2.[63] Maintenance Rates for Patents by Technology Class

Class	Description	Maint. Rate
482	Exercise Equipment	21%
473	Golf Clubs/Equipment	26%
446	Toys and Amusement Devices	30%
206/250	Packaging	43%
365/364	Computers	55%
935	Genetic Engineering	56%

62 Table 1 is developed from a random sample of 70,000 patents issued in 1986, based upon data reported in THE OFFICIAL GAZETTE OF THE UNITED STATES PATENT & TRADEMARK OFFICE and available through Delphion at www.delphion.com.

63 Table 2 is developed from data reported in THE OFFICIAL GAZETTE OF THE UNITED STATES PATENT & TRADEMARK OFFICE for patents issued 1983-1987 and available through Delphion at www.delphion.com.

EXHIBIT 76

Econometrica, Vol. 54, No. 4 (July, 1986), 755–784

PATENTS AS OPTIONS: SOME ESTIMATES OF THE VALUE OF HOLDING EUROPEAN PATENT STOCKS

BY ARIEL PAKES[1]

In many countries patentees must pay an annual renewal fee in order to keep their patents in force. This paper presents and then estimates a model which uses observations on the proportion of different cohorts of patents which are renewed at alternative ages, and the relevant renewal fee schedules, to estimate the distribution of the returns earned from holding patents, and the evolution of this distribution function over the lifespan of the patents. Since patents are often applied for at an early exploratory stage of the innovation process, the model allows patentees to be uncertain about the sequence of returns that will be earned if the patent is kept in force. The paper solves the implied optimal stopping problem for the micro units, derives the implications of these solutions on the aggregate proportions renewed, and then estimates the parameters of the model from the aggregate data. Separate estimates are obtained from data on post World War II cohorts of patents in each of France, the United Kingdom, and Germany.

KEYWORDS: optimal stopping, maximum likelihood, simulation estimator, patent rights, renewal fees, option values, the value of patent protection.

IN MANY COUNTRIES holders of patents must pay an annual renewal fee in order to keep their patents in force. If the renewal fee is not paid in any single year, the patent is permanently cancelled. Assuming that renewal decisions are based on economic criteria, agents will only renew their patents if the value of holding those patents over an additional year exceeds the cost of renewal. Observations on the proportions of different cohorts of patents which are renewed at alternative ages, together with the relevant renewal fee schedules, will, in this case, contain information on the distribution of the values of holding patents, and on the evolution of this distribution function over the lifespan of the patents. Since patent rights are seldom marketed, this is one of the few sources of information on the value of patents available. This paper presents and then estimates a model which allows us to recover the distribution of returns from holding patents at each age over the lifespan of patents from information on patent renewals. Separate estimates are obtained from data on post World War II cohorts of patents in each of the United Kingdom, France, and Germany (renewal fees were not instituted in the United States until 1982). These estimates enable calculations

[1] I have benefited from the comments of many individuals in the course of this study, among them John Bound, Zvi Griliches, Bronwyn Hall, Jerry Hausman, James Heckman, Tom Kurtz, Charles Manski, Daniel McFadden, Andrew Meyers, Dvora Ross, John Rust, Mark Schankerman, three referees, and an editor of this journal. I am particularly indebted to Charles Manski and Zvi Griliches for a series of discussions which contributed a great deal to the development of this paper; and to James Heckman, John Rust, and the participants in an informal seminar chaired by Charles Manski and Daniel McFadden for comments that facilitated the solution to various problems. This paper is an offshoot of ongoing research with Mark Schankerman. The research was supported by the NSF through Grant PRA 81-08635. I am thankful to Andrew Meyers, Dvora Ross, and Tom Abbott for superb programming assistance. All errors, of course, remain my responsibility.

also have two local maxima (and at the same ages), but the model's estimates of these maxima are somewhat too high, and its estimate of the trough between them is too low. In Germany the data provide a rather flat age distributon of average drop out proportions between ages eight and eleven. The model's estimates replace this with two local maxima and a minimum, though neither the maxima nor the minimum are nearly as pronounced as those estimated for the earlier ages in France. In addition, the model's estimates of the average drop out proportions in the later ages are a bit too high in France, and a bit too low in Germany. In sum, though Figures 4 and 5 indicate why the mean square error of the differences between the observed and estimated proportions are small relative to $V(\tilde{\pi}; \text{data})$, they also indicate that the model is not perfectly specified, and this should be kept in mind when considering the implications of the parameter estimates.[15]

Table IV provides a summary of the distribution of returns at ages one, three, and five respectively. Two implications of this table are of interest. First there is a distinct pattern to the evolution of these distribution functions over age. Between ages one and three the upper tail of the distribution becomes thicker and is pushed to the right. That is, a substantial fraction of the patentees who had the "upside draws" in Table III uncovered uses for their patented ideas which increased the returns earned from holding their patents by large amounts. A comparison of the quantiles for age five to those of age three reveals the onset of the obsolescence process; that is, the quantiles from the age five distribution are always below the same quantiles from the distribution at age three. The second point to note is that there is a skew in the initial distribution of returns,

TABLE IV[a]

THE DISTRIBUTION OF RETURNS IN THE EARLY AGES [$F(r, a)$]

Country	France			Germany		
r/a	1	3	5	1	3	5
0	0	.155	.270	0	.001	.04
50	.31	.315	.375	.01	.01	.04
150	.580	.525	.585	.07	.065	.095
500	.830	.710	.745	.34	.27	.325
2,500	.975	.86	.895	.83	.655	.705
5,000	.990	.925	.950	.940	.800	.845
15,000	.995	.990	.990	.990	.95	.97

[a] See the note to Table III.

[15] Given the values of *NSIM* and *NPAT* for our problem (see Table I) the binomial sampling error in both the empirical and estimated frequencies have variances very close to zero. As a result even our, relatively small, sample values of MSE($\tilde{\pi}$) are too large for sampling variance to be the only source of error in the model. Though this problem, which is called the problem of extra-binomial sampling variance by Williams (1982) (see also the review in Haseman and Kupper (1979) and the discussion in Heckman and Singer (1984)), occurs frequently in models designed to analyze proportions when the underlying sample size is large, I do not know of any consistent way of accounting for it when the model has a sequential dimension.

and that this skew increases substantially over the first few ages. This fact leads to a highly skewed distribution of realized patent values.

Table V provides percentiles and Lorenz curve coefficients from the distribution of realized patent values, where the realized value of a patent is defined as the discounted sum of net returns (current returns minus renewal fees) from age one to the last age the given patent is kept in force. Again I begin by considering the column of figures for France. Twenty-five per cent of the patents in the French data had realized values of seventy-five dollars or less.[16] These patents contributed about a half of one per cent to the total value of the patents in a cohort, while the patents in the lower half of the distribution contributed less than two per cent of the total value of a cohort. The median of the distribution of realized values ($534) was less than one tenth its mean ($5,631); and the five per cent of the distribution with the highest realized values contribute about half of the total value of a cohort. The German distribution of realized values was somewhat less skewed than the distribution in France, though even the German distribution was extremely skewed. The difference between the two distributions was, as might have been expected from the fact that in Germany the data refer to grants rather than applications, most pronounced at the lowest percentiles. In Germany these percentiles were nonnegligible, albeit, quite small. Still only about 7 per cent of the patents in Germany had realized values in excess of $50,000; in France only

TABLE V

PERCENTILES (p1) AND LORENZ CURVE COEFFICIENTS (1c) FROM THE DISTRIBUTION OF REALIZED PATENT VALUES[a]

	Country					
	France		U.K.		Germany	
Per cent p	p1 ($)	1c per cent	p1 ($)	1c per cent	p1 ($)	1c per cent
.25	75.23	.544	355.55	.554	1,999.60	2.249
.50	533.96	1.833	1,516.84	3.247	6,252.93	7.341
.75	3,731.35	8.087	7,947.55	16.369	19,576.26	25.288
.85	10,292.06	19.575	15,357.09	31.721	32,428.14	41.001
.90	17,423.11	31.261	22,206.21	44.257	44,241.87	52.672
.95	31,609.59	52.461	34,740.07	62.960	65,753.61	69.223
.97	42,905.78	65.514	43,889.95	73.640	78,299.01	78.348
.98	51,215.84	73.729	51,277.22	80.072	94,842.63	83.800
.99	66,515.40	84.011	65,075.08	87.858	118,354.78	90.330
maximum	259,829.27	—	374,028.70	—	419,217.55	—
mean	5,631.03	—	7,357.05	—	16,169.48	—
$\overline{NPAT}$	36,865		37,826		21,273	

[a] The realized value for patent i is $\sum_{\tau=1}^{\tau_i^*} \beta^{(\tau-1)}(r_{i,\tau}-c_\tau)$, where τ_i^* is the last age at which patent i was kept in force. See also the note to Table III.

[16] Of course some of these patents had negative (though small in absolute value) realized values, as they were patents on which early renewals were paid for options which did not materialize. If, for example, we had defined the realized values as the discounted sum of net returns from age two, rather than from age one (as in the table), the Lorenz curve coefficient corresponding to $p = .25$ would have been negative, though close to zero.

two and a half per cent had values this large. Given the size of the cohorts this implies that, on average, about a thousand patents which had realized values in excess of $50,000 were applied for annually in France, and about fifteen hundred such patents were granted annually in Germany.

One other point is worthy of note here. The estimate of the ratio of the average realized value in a cohort of patents applied for in France, to that value in a cohort of patents granted in Germany, is .35—which is just equal to the average of the ratios of grants to applications in the German cohorts (see Table I). The estimates seem to imply, then, that the mean of the realized values of the patents applied for in the two countries was similar. On the other hand, there were a significantly larger number of patents applied for per year in Germany than in France (about 60,780 in Germany, versus 36,865 in France). On average, then, the total value of a cohort of patents in Germany was larger than the value of a French cohort.

4.3. *The Value of Patent Protection and the Characteristics of the Patenting Process*

A word of caution is in order before proceeding. Though it may well be the case that the patent renewal data are the most extensive and detailed information source on the value of patent protection available, they, in themselves, contain only a limited amount of information: the age path of the proportion of patents in different groups paying a renewal fee and the renewal fee schedules. Mixing this information with additional assumptions has lead to a set of quite detailed conclusions, but it should be clear that these may depend on the additional assumptions chosen (both behavioral and stochastic). The only exogenous check of these conclusions I have considered is a broad check of the implications of the parameter estimates against known intercountry differences in the data. In this section I consider more general implications of the parameter estimates. Though here it will be possible to provide rough checks for the consistency of some of the conclusions we derive with alternative sources of information, it should be kept in mind that there may be many models that do as well as ours in all these respects (as well as in fit), but differ substantially in others.

To get an indication of the annual returns earned from holding the patent stock in a country, we must account for the fact that the patent stock held at a given point in time consists of the patents from the cohorts applied for over the previous L years which are still in force at that time. Assuming that each of the previous L cohorts began with the average number of patents per cohort and faced the mean of the renewal fee schedules, and using the parameter estimates of Table II, we find that the net annual flow of returns from holding the patent stocks in France, the U.K., and Germany were .315, .385, and .512 billion dollars, respectively. To consider whether these figures imply large gains from patenting we would like to compare them to either the total returns that accrued to the patented ideas, or to the expenditures that went into developing them. Neither of these two numbers are available, but the OECD (1975; Tables III and IV) does provide estimates of the R&D expenditures funded by the business enter-

prises in these countries in 1963 (which is the midcohort in our data). The estimates of the annual returns from holding the patent stocks were respectively, 15.56 per cent, 11.03 per cent, and 13.83 per cent of the R&D expenditures of the business enterprises in France, the U.K., and Germany; and the sum of these returns across countries was 13.14 per cent of the sum of their R&D expenditures. Since there may be returns earned as a result of patenting per se, regardless of whether the patents were ever renewed, and since our estimates only pertain to the returns earned by renewing (or holding) patents already in force, the numerator of this ratio may slightly understate the annual monetary value of the incentives created by the patent system. Moreover, the ratio suffers from the fact that we have not netted out various balance of trade effects.[17] Still, the ratio does suggest that the proprietary rights resulting from the patent laws create annual returns which are nonnegligible in comparison to privately funded R&D activity.

The returns earned from holding patents may, of course, be only a small fraction of the returns that accrue to patented ideas. Nevertheless the general similarity between the shape of the estimated distributions of the value of holding patents on the one hand (see Table V), and currently available evidence on the distribution of the values of patented ideas on the other, is quite striking. In particular the evidence available from disaggregated case studies indicates an extremely skewed distribution of the values of patented ideas (see Sanders, Rossman, and Harris (1958); and Gabrowski and Vernon (1983)). Scherer (1958, p. 1098), for example, notes that the data provided in Sanders, Rossman, and Harris suggest a Pareto-Levy distribution with an infinite mean for the distribution of profits from patented ideas; while Garbrowski and Vernon summarize their studies on the profitability of new pharmaceutical entities with the statement: "In effect, these results indicate that pharmaceutical firms are heavily dependent on obtaining an occasional "big winner" to cover their R&D costs and generate profits" (Gabrowski and Vernon, 1983, p. 11). Larger sample econometric studies have focused on the relationship between the number of patents applied for and alternative measures of the outputs and the inputs into inventive activity (see the articles in Griliches (1984)). Pakes (1985) provides a detailed time-series cross-section analysis of the reduced form relationship between patent applications, R&D expenditures, and changes in the stock market value of firms, that allows for dynamic error components to intercede between these variables. That article concludes that changes in the number of patents applied for by firms are a very noisy measure of the changes in stock market value of their R&D related output, but that, on average, increases in patent applications are associated with large increases in the firm's value, just what we would expect from a highly skewed distribution of the value of patented ideas. In addition, a strong simultaneous relationship between the factors driving R&D expenditures and those driving patents was found, suggesting that a significant search for uses and improvements to the patented ideas continues during the early years of a patent's life.

[17] Business enterprises in these countries also own patents in force elsewhere, and foreign business enterprises own patents in force in these countries. Moreover, not all the business sector's R&D expenditures are directed towards patentable innovations, and not all patentees are business enterprises.

There is an explanation of the patenting process which is at least consistent with both the empirical results found in this paper, and with those cited above. Patents are applied for at an early stage in the inventive process, a stage in which there is still substantial uncertainty concerning both the returns that will be earned from holding the patents, and the returns that will accrue to the patented ideas. Gradually the patentors uncover the true value of their patents. Most turn out to be of little value, but the rare "winner" justifies the investments that were made in developing them. If this explanation captures the nature of the patenting process we would not expect to find a very stable relationship between profits and current and past patents, or between profits and the current and past R&D expenditures which lead to them, except possibly for very large aggregates. For individual economic units we would expect most increases in patents not to lead to any increase in profits, and for there to be an occasional jump in profits which is not necessarily preceded by any increase in patenting. Growth through discovery will occur in spurts, and these spurts will be probabilistically related to the investments which preceded them. Traditional production function approaches to obtaining estimates of either the rate of return to the investments which produced the patents, or the determinants of the quantity of resources invested in their development, are not likely to be very precise. Nor will they provide much evidence on the characteristics of the distribution of possible outcomes, features of the problem that are likely to be particularly important in analyzing the rich set of issues determining the evolution of firm and industry structure. An alternative, pointed out by Nelson and Winter (1982), and Telser (1982), is to be more careful in the econometric modelling of the inventive process itself, employing, perhaps, controlled search processes in which investment expenditures affect the distribution of possible outcomes.[18]

One final point: Disaggregated patent renewal data, data which enable an investigation of the returns to patent protection by technical field of the patent and by nationality and type of patentor (e.g. individuals, small business enterprises, large corporate entities), is gathered by INPADOC (International Patent Documentation Center, Vienna, Austria). These data should prove extremely valuable. Issues related to which sectors of a particular economy, and which economies, derive disproportionate benefits from the patent laws lie at the heart of most discussions of the cost and benefits of alternative patent systems (see Scherer (1965, Chapter 16), and the literature cited there). Moreover, intersectoral differences in the patenting and R&D processes are central to the literature on market structures, industrial policy, and technical progress.

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APPENDIX A

This appendix proves the following lemma.

LEMMA 1: *The value of the option, that is,* $E[V(a+1)|r, a]$, *is*: (*i*) *continuous and nondecreasing in* r, *and* (*ii*) *nonincreasing in* a ($r \in R_+$, $a = 1, \ldots, L$).

[18] A step in this direction has been made by Ericson and Pakes (1983).

PROOF: The proofs of both (i) and (ii) are obtained by backward induction on "a", and use the following lemma (for a proof, see Ross (1983, p. 154)). Let $f(z)$ be nondecreasing in z and $\Pr\{z \le k | z_1\} \le \Pr\{z \le k | z_1'\}$ for all $k \in R_+$. Then, provided $E[f(z)|z_1] < \infty$, $E[f(z)|z_1] \ge E[f(z)|z_1']$ (for nonincreasing $f(\cdot)$, $E[f(z)|z_1] \le E[f(z)|z_1']$).

Part (i). Since $E[V(L+1)|r] = 0$ for all r, the initial condition of the inductive argument is satisfied trivially, and it suffices to show that if the proposition is true for $a = \tau+1$, it is also true for $a = \tau$. Recall that $V(\tau+1, z) = \max\{0, z - c_{\tau+1} + \beta E[V(\tau+2)|z, \tau+1]\}$, and note that since the hypothesis of the inductive argument implies that $E[V(\tau+2)|z, \tau+1]$ is continuous and nondecreasing in z, $V(\tau+1, z)$ is also.

To establish continuity take any $r \in R_+$. $E[V(\tau+1)|r, \tau]$ will be continuous at r if for every sequence $\{r_n\}$ such that $\lim r_n = r$ (or $r_n \to r$), $E[V(\tau+1)|r_n, \tau] \to E[V(\tau+1)|r, \tau]$ (Royden (1968, p. 48). For any such sequence, let $V_n(\tau+1)$ be the random variable $V(\tau+1, z)$ with distribution $G(z|r_n, \tau)$ ($V(\tau+1)$ has distribution $G(z|r, \tau)$). Since A3.2 implies that $G(z|r_n, \tau)$ converges in distribution to $G(z|r, \tau)$, and $V(\tau+1, z)$ is continuous in z, the distribution of $V_n(\tau+1)$ converges to that of $V(\tau+1)$ (Billingsley (1979, Theorem 25.7)). This fact will insure that $E[V(\tau+1)|r_n, \tau] \to E[V(\tau+1)|r, \tau]$, if there exists an $\varepsilon > 0$ for which $E[V(\tau+1)]^{1+\varepsilon}|r_n, \tau] < \infty$ for all n (Billingsley (1979, Theorem 25.12 and its corollary)). Note also that since r was arbitrary, if we show that $E[V(\tau+1)]^{1+\varepsilon}|r_n, \tau] < \infty$, then $E[V(a+1)|r, a]$ is continuous in r for all $r \in R_+ (a = 1, \ldots, L)$.

Now

$$E[V_n(\tau+1)^{1+\varepsilon}] \le E\left[\left(\sum_{j=1}^{L-\tau} r_{\tau+j}\right)^{1+\varepsilon} \middle| r_\tau = r_n\right] \le 2^\varepsilon \sum_{j=1}^{L-\tau} E[r_{\tau+j}^{1+\varepsilon} | r_\tau = r_n]$$

(Rao, 1973, p. 149). Since Assumption A3.1 insures that there exists an $\varepsilon > 0$ such that $E[r_{1+j}^{1+\varepsilon}|r = r_n] < \infty$, it will suffice to show that $E[r_{\tau+j}^{1+\varepsilon}|r_\tau = r_n] \le E[r_{1+j}^{1+\varepsilon}|r_1 = r_n]$, for all n and $j = 1, \ldots, L-1$.

For this we require only that

$$G_{\tau,j}(k|r_n) \equiv \Pr\{k \ge r_{\tau+j}|r_\tau = r_n\} \ge \Pr\{k \ge r_{1+j}|r_1 = r_n\} \equiv G_{1,j}(k|r_n)$$

for all $k, j = 1, \ldots, L-\tau$, and $r_n \in R_+$. A second inductive argument proves this point. Since Assumption A3.4 insures the inequality for $j = 1$, it will suffice to show that if the inequality is true for $j = j'$, it is also true for $j = j'+1$. Now

$$\begin{aligned}
&\Pr\{k \ge r_{\tau+j'+1}|r_\tau = r_n\} \\
&\quad = \int G(k|z, \tau+j') G_{\tau,j'}(dz|r_n) \\
&\quad \ge \int G(k|z, 1+j') G_{\tau,j'}(dz|r_n) \\
&\quad \ge \int G(k|z, 1+j') G_{1,j'}(dz|r_n) = \Pr\{k \ge r_{2+j'}|r_1 = r_n\}
\end{aligned}$$

where the first inequality follows from A3.4, and the second from the hypothesis of the inductive argument and the Lemma since $G(k|z, 1+j')$ is nonincreasing in z (from A3.3) and bounded by 1.

To establish that $E[V(\tau+1)|r, \tau]$ is nondecreasing in r apply the Lemma directly and note that: $V(\tau+1, z)$ is nondecreasing in z (from the hypothesis of the inductive argument); $G(z|r, \tau) \le G(z|r', \tau)$ whenever $r \ge r'$ (from A3.3); and $V(\tau+1, z)$ is integrable with respect to $G(z|r, \tau)$ (from the argument given above). *Q.E.D.*

Part (ii). For the first step of the inductive argument I assume that $E[V(a+2)|r, a+1] \le E[V(a+1)|r, a]$ and show that this implies that $E[V(a+1)|r, a] \le E[V(a)|r, a-1]$ for $r \in R_+$. Recall that $V(a+1, z) = \max\{0, z - c_{a+1} + \beta E[V(a+2)|z, a+1]\} \le \max\{0, z - c_a + \beta E[V(a+1)|z, a]\} = V(a, z)$, where the inequality follows from the hypothesis of the inductive argument and the fact that $c_{a+1} \ge c_a$ (see A2). Therefore, for any $r \in R_+$,

$$\begin{aligned}
E[V(a+1)|r, a] &= \int V(a+1, z) G(dz|r, a) \le \int V(a, z) G(dz|r, a) \\
&\le \int V(a, z) G(dz|r, a-1) = E[V(a)|r, a-1],
\end{aligned}$$

where the last inequality follows from the Lemma, since $V(a, z)$ is nondecreasing in z and integrable with respect to $G(z|r, a-1)$ (see above), and $G(z|r, a) \ge G(z|r, a-1)$ from Assumption A3.4. To establish the initial condition for the inductive argument it suffices to note that $E[V(L+1)|r, L] = 0 \le \int_{c_L} (z - c_L) G(dz|r, L-1) = E[V(L)|r, L-1]$. *Q.E.D.*

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A dynamic stochastic analysis of international patent application and renewal processes ☆

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ABSTRACT

This paper formulates a dynamic stochastic model to examine the joint patent application and renewal behaviors under an international patent-protection regime. The framework makes it possible to utilize both the cross-sectional (multi-country application) and the time-series (patent renewal) dimensions of available international patenting data to estimate the private value of patent protection, and allows us to distinguish more aspects of patent returns. The evolution dynamics of the value of European patents in pharmaceutical and electronics industries are examined. Estimation results indicate that pharmaceutical patents are endowed with higher initial returns, thus their owners tend to seek patent protection in more countries than electronics patent holders. However, pharmaceutical patents become obsolete at a much faster pace than electronics patents, and consequently they have lower renewal rates and shorter lives.

1. Introduction

During the past two decades, patent evaluation has attracted considerable academic scrutiny, for both public policy analysis and commercial purposes. As patent value is not directly observable, researchers have experimented with many different approaches to impute it, using various patent characteristics such as simple patent counts (Griliches, 1990), forward citations made by other patents (Trajtenberg, 1990; Lanjouw and Schankerman, 2004; Hall et al., 2005), the length of patent lives (most notably Pakes and Schankerman (1984), Pakes (1986), Lanjouw (1998), and Schankerman (1998)), and the family size of patents (*i.e.*, the number of countries in which a patent holder seeks patent protection — Putnam (1996), Eaton et al. (2003) Deng (2007)).

This paper extends the existing literature by developing a dynamic stochastic patent application–renewal model and examining the joint determination of patent family size and length of patent life, thus facilitates the combination of information from both dimensions to estimate the distribution of patent value. Most relevant studies in the literature either focus only on patent renewal (Lanjouw, 1998; Pakes, 1986), or on patent application with a deterministic evolution for patent returns (Deng, 2007; Putnam, 1996), but never on a stochastic framework which can be used to jointly examine patent application and renewal behaviors and identify the stochastic evolution of patent returns over patent lives. This paper builds such a framework, in which a representative patent applicant has to estimate, *ex-ante*, how potentially valuable his invention will be in each country and decides in which countries to seek patent protection. After the patent application has been granted, the patent holder then updates his evaluation of the patent rights in each country based on information he gradually learns, period by period, and decides whether to keep the patents alive in each country, until they finally lapse.

In examining patent holders' renewal behavior, one needs to realize that patent renewal is an optimizing process, during which a patent holder compares the renewal costs with the expected future returns of the patent and decides how long the patent should be kept alive. Thus the length of a patent's life reveals useful information about the patent's private value to its owner. Similarly, in choosing which countries in which to seek patent protection, a prospective applicant would also compare the application costs with the expected future returns in each country, and decide which countries in which to apply. Applicants with high-valued inventions tend to seek protection in more countries, *ceteris paribus*. Therefore, examining the joint distribution of family size and the length of patent life across different countries will allow us to distinguish more aspects of the patent value, and advance our understanding of how the patent value changes over time as well as across different countries.

Examining patents' joint application–renewal behavior may also shed light on some puzzles implied by the patenting data. Normally,

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Table 2
Model estimation results.

	Pharmaceutical	Electronics
A. Parameter[a]		
θ	0.95 (0.03)	0.98 (0.02)
δ	0.95 (0.03)	0.96 (0.03)
σ	3575 (413)	2380 (358)
ϕ	0.61 (0.06)	0.70 (0.07)
γ	0.55 (0.05)	0.49 (0.05)
υ	1.04 (0.09)	1.38 (0.07)
μ_α	9.08 (0.83)	8.33 (0.74)
σ_α	2.07 (0.38)	1.74 (0.33)
σ_ε	1.35 (0.24)	1.53 (0.27)
τ	3.06 (0.27)	2.75 (0.26)
Dummy 82–83	0.14 (0.04)	0.00 (0.03)
Dummy 84–85	0.24 (0.05)	0.07 (0.04)
B. Size of		
B1. Sample	12,329	56,737
B2. Simulation	36,987	170,221
B3. Cohort–age–country cells	312	312
C. Summary statistics[b]		
C1. MSE($\tilde{\pi}$)	0.0328	0.0582
C2. V(π)	0.0852	0.1402
C3. MSE($\tilde{\pi}$)/V(π)	0.3849	0.4151
C4.MSE($\tilde{\pi}_{desig}$)/V(π_{desig})	0.4396	0.4859
C5. MSE($\tilde{\pi}_{renewal}$)/V($\pi_{renewal}$)	0.3115	0.2997

[a] Estimated standard errors are reported in parentheses.
[b] MSE is calculated as the sum of squared residuals weighted by the number of patents in each cohort–age–country cell. V(π) is the sample variance from the data.

improvement of our model's performance over such a "naive" model, similar to a $(1-R^2)$ statistic in linear regressions. As shown in row C3 of Table 2, compared with the "naive" model, the joint application–renewal model improves the fitness of data by about 63% for pharmaceutical patents and about 58% for electronics.

To separately examine the model's performance in fitting designation and renewal patterns, the total weighted MSE is decomposed into two parts, one in matching the designation rates (row C4) and the other in matching the renewal rates (row C5). By comparing them with the variance of the corresponding actual designation and renewal rates in the sample, we conclude that the estimated model performs well in both dimensions. For instance, it improves over the "naive" model by 56% in fitting the pharmaceutical designation pattern and 51% in fitting the electronics designation pattern, and by 69% and 70% in fitting the renewal pattern of these two patent groups, respectively.

4.1. Obsolescence and depreciation dynamics

The estimates of model parameters are all positive and significant. The estimated deterministic depreciation rate δ is fairly close in the two patent groups: each year patent returns depreciate by 4–5% in both technology fields. The estimate of the annual obsolescence rate θ, however, is quite different between the two groups. In particular, each year about 2% of electronics patents become obsolete, but the obsolescence rate is more than doubled among pharmaceutical patents, about 5%. This is consistent with the observation of a shorter average life for pharmaceutical patents in the data analysis in Section 3. We will explore possible explanations for different obsolescence dynamics in these two technology fields below.

4.2. Learning dynamics

Model estimation also implies that parameter σ for the pharmaceutical patents, which characterizes the stochastic learning processes, is significantly higher than that of the electronics patents. For a patent with a given value, a larger σ implies a larger probability of learning a higher value. Therefore, pharmaceutical patents may benefit from a more productive learning process at early ages, which tends to boost their expected returns over time.

However, the comparison of learning processes between these two technology fields is complicated by parameter estimates of ϕ, the decay rate of σ_t. Recall that parameter σ_t is defined as $\sigma_t = \sigma\phi^{t-1}$ in Eq. (2.3). The estimate of the decay rate ϕ is 0.61 for pharmaceutical patents and 0.70 for electronics patents. In other words, although a pharmaceutical patent may have a higher initial learning probability (a higher σ), such probability declines more quickly. And starting from age 5, σ_t of the pharmaceutical patents becomes smaller than that of the electronics patents. The estimates of the other parameter of the exponential distribution, γ, are similar for these two technology groups.

It might be more straightforward to simulate the learning process in these two patent groups and examine the implications of these different parameter estimates. Table 3 illustrates the results of a simulation run of cohort group 1980–1981 patents, based on the parameter estimates as reported in Table 2. Columns 2 to 4 of the table display the percentage of the simulated pharmaceutical patents learning a higher value at each age in Germany, France and the U.K., out of all patents that live up to that age. For instance, at the beginning of age 2, 17% of the pharmaceutical patent applicants discover a use which generates higher subsequent returns than known before in France, 9% in Germany and 7% in the U.K.; at age 3, the learning probability drops to 11% in France, 6% in Germany, and 4% in the U.K. The learning probability continues to decline over time. By age 5, about 2% to 6% of the pharmaceutical patent holders find more profitable ways to exploit their patented ideas in these three countries, and the learning process of pharmaceutical patents is essentially over by age 11 in Germany and the U.K. and by age 12 in France. After that, the deterministic depreciation and obsolescence processes begin to dominate the evolution of patent returns.

Columns 5 to 7 of Table 3 report the simulated learning dynamics of the electronics patents. Similar to the case of pharmaceutical patents, the learning probability in this group also gradually declines over time, in Germany from 10% at age 2 to 4% at age 5, and the learning is essentially over by age 11. In France, learning probability drops from 13% at age 2 to 5% at age 5, and essentially to zero after age 12. Such probability is 15% in the U.K. at age 2 and 6% at age 5, and the learning is over after age 12 as well.

The fact that the dynamics of learning probability is similar in pharmaceutical and electronics patent groups reflects offsetting effects of different parameters of the learning processes in these two groups. As noted above, the parameter σ_t in the learning process of pharmaceutical patents is initially higher than that of electronics patents, which generates higher probabilities of discovering a higher value for any given level of patent value. However, because the initial returns of pharmaceutical patents are on average higher than those

Table 3
Percentage of pharmaceutical and electronics patents learning a higher value.

	Pharmaceutical (%)			Electronics (%)		
Age	Germany	France	U.K.	Germany	France	U.K.
2	8.95	17.31	7.19	9.72	13.16	14.80
3	5.58	10.87	4.44	6.14	8.29	9.32
4	4.84	9.31	3.21	6.15	7.86	9.64
5	2.58	5.95	1.64	3.61	4.72	5.56
6	0.99	2.93	0.90	1.95	2.59	3.22
7	0.36	1.15	0.30	0.98	1.33	1.59
8	0.07	0.55	0.08	0.46	0.71	0.76
9	0.04	0.22	0.03	0.11	0.31	0.23
10	0.01	0.06	0.01	0.04	0.11	0.05
11	0.00	0.02	0.00	0.00	0.04	0.01
12	0.00	0.00	0.00	0.00	0.00	0.01

Note: Table 3 reports the learning probability from a simulation run of cohort group 1980–1981 patents (nsim = 3), based on the parameter estimates reported in Table 2.

of electronics patents (as shown below in Table 4), the actual probability of finding a return exceeding the present level may not necessarily be higher than that of the electronics patents. The first few rows of Table 3 show that the learning probability of pharmaceutical patents at early ages is slightly higher than that of electronics patents in France but lower in Germany and the U.K. Moreover, the parameter σ_t of pharmaceutical patents declines faster over time, and by age 7 it becomes significantly lower than that of electronics patents in all three countries. From then on, the learning probability of pharmaceutical patents is consistently lower than the corresponding probability of electronics patents.

Pakes (1986) reports that in a sample of German and French patents in the 1950s to 1970s, the learning process is essentially over by the age of 5. Lanjouw (1998) shows that the learning stops by age 6 or 7 in all technology groups in her sample of German patents in 1953 to 1988. In contrast, model estimation here indicates a significantly longer learning process during the life of EPO patents. This suggests that EPO patents have quite different characteristics from the national patents studied in previous literature, most likely, a higher average quality. As the EPO is a multi-country patent protection regime with higher application costs, only those applicants who decide to seek protection in more than one country will choose to apply (otherwise they may choose the cheaper national route in the single country in which they are interested). This selection process leads to a higher quality on average in the EPO sample than national patent samples examined in previous studies. Owners of these higher-quality patents would expect higher patent values and are thus more willing to experiment with new strategies to exploit the patented ideas. On the other hand, the higher revenues from implementing these patented ideas, especially at early ages, also provide their owners more resources for such explorations.[6]

Table 4
Distribution of the initial returns of simulated patents.

	Pharmaceutical					
	50%		90%		99%	
	Value ($ thou)	Cum. %	Value ($ thou)	Cum. %	Value ($ thou)	Cum. %
Austria	0.64	0.48%	14.88	8.16%	211.78	30.21%
Belgium	0.33	0.78%	7.53	13.18%	95.75	47.45%
Switzerland	3.74	0.64%	85.10	10.76%	1144.55	41.90%
Germany	8.61	0.61%	210.35	10.38%	2585.70	39.40%
France	1.43	0.82%	31.69	13.52%	445.06	50.01%
U.K.	7.65	0.64%	169.80	10.65%	2301.24	39.36%
Italy	1.58	0.69%	36.15	11.32%	466.66	42.71%
Luxembourg	0.05	0.68%	1.07	11.37%	15.01	42.72%
Netherlands	4.49	0.73%	96.71	12.06%	1300.58	44.50%
Sweden	0.95	0.73%	21.64	12.21%	308.56	48.02%
	Electronics					
	50%		90%		99%	
	Value ($ thou)	Cum. %	Value ($ thou)	Cum. %	Value ($ thou)	Cum. %
Austria	0.09	1.05%	1.65	15.28%	19.12	51.42%
Belgium	0.04	1.03%	0.68	15.02%	7.42	49.09%
Switzerland	0.11	1.02%	2.29	15.31%	24.35	51.09%
Germany	4.08	0.99%	81.91	14.76%	897.71	49.48%
France	2.60	0.95%	49.88	13.87%	554.31	45.91%
U.K.	1.77	1.00%	34.72	14.74%	374.23	47.49%
Italy	0.84	1.04%	16.39	15.24%	186.78	51.82%
Luxembourg	0.01	0.94%	0.15	14.02%	1.63	46.33%
Netherlands	0.93	1.02%	17.94	14.89%	201.45	49.49%
Sweden	0.17	1.02%	3.44	15.18%	40.35	51.63%

Note: Table 4 reports the distribution of the initial patent returns (prior to the designation decision being made) in each of the 10 EPO member countries, based on a simulation run of cohort group 1980–1981 patents. Columns 2, 4, 6, 8, 10 and 12 display the initial returns of the patents, and columns 3, 5, 7, 9, 11 and 13 display the cumulative proportions of the initial returns in the total initial returns of the simulated patent group in each country. All monetary values are in units of 2000 U.S. dollars.

4.3. Returns to market sizes

The estimated value of v is significantly different from zero, implying that the patent value in a given country is highly correlated with the market size of the country and increases as the size of the economy increases, *i.e.*, a larger market generates higher returns to patent holders. However the estimated degree of returns to scale differs significantly in the two technology fields: pharmaceutical patents exhibit approximately constant returns to scale, while electronics patents show significantly increasing returns to scale. For example, the market size of Austria is approximately 10% of that of Germany, as measured by the ratio of their real GDPs, and model estimates imply that the median initial return of a pharmaceutical patent in Austria is about 9.1% of that in Germany. However, for electronics patents, the median initial return in Austria is only 4.2% of that in Germany. Previous patenting literature has provided little evidence regarding the degree of returns to scale in different countries. Researchers such as Putnam (1996) generally make an *ad hoc* assumption of constant returns to scale.

Estimates of this returns-to-scale parameter have important policy implications. For instance, our estimates suggest that electronics inventors may benefit more from market integration and patent harmonization in Europe than pharmaceutical inventors in terms of patent protection, other things being equal. This is because the value of an electronics invention in a unified European market would be significantly higher than the sum of values in individual national markets due to increasing returns to scale, whereas for a pharmaceutical invention the value would be almost the same.

The exact reason for such a difference remains unclear, yet we suspect that it may be closely related to the different characteristics of these two technology fields: pharmaceutical products are usually based on a single or only a few specific inventions ("discrete" technology as characterized by Levin et al. (1987)), and because the sales of the final products in different countries usually increase at a constant rate as the market size or the population increases, the patent value would naturally exhibit a constant returns to scale. The production of electronics, on the other hand, may rely on various technologies embodied in a large number of inventions ("complex" technology, same above), and a substantial part of patent payoffs are obtained through arrangements such as cross-licensing agreements. In countries with a larger economy and a larger electronics industry, a patent holder may find more uses and more possibilities to negotiate cross-licensing agreements than in countries with a smaller economy. Therefore it is not surprising that the patent value in this group shows increasing returns to scale, as a positive externality or spillover effect may occur when various electronics patents are combined.[7]

The estimate of τ also indicates significant correlations between patent returns across different destination countries. Moreover, such

[6] Alternatively, there might also be a general increase in the overall quality of patent applications from the 1950s to the 1980s, although literature has not found firm evidence supporting such a conjecture.

[7] Levin et al. (1987), Merges and Nelson (1990), Kusonaki et al. (1998), Kash and Kingston (2000), and Cohen et al. (2000) all recognize this distinction between "discrete" and "complex" technologies. As Cohen et al. (2000) explain, "the key difference between a complex and a discrete technology is whether a new, commercializable production or process is comprised of numerous separately patentable elements *versus* relatively few," and "new drugs or chemicals typically are comprised of a relatively discrete number of patentable elements. In contrast, electronic patents tend to be comprised of a larger number – often hundreds – of patentable elements and, hence, may be characterized as complex." Hall et al. (2005) also argue that the "drug industry is characterized by discrete product technologies where patents serve their traditional role of exclusion … while as computers and communications is a group of complex product industries where any particular product may rely on various technologies embodied in several patents."

correlations decrease as the geographical distance increases. For instance, correlations between the idiosyncratic shocks to pharmaceutical patent returns in Germany and Austria are 0.36, and the correlations decline to 0.18 between Germany and France and to 0.10 between Germany and Italy; correlations between France and Belgium are as high as 0.60, and decline to 0.43 between France and Switzerland and 0.05 between France and Sweden. Cross-country correlations between electronics patents are slightly higher: 0.41 between Germany and Austria, 0.22 between Germany and France and 0.13 between Germany and Italy. Whether such high correlations reflect cross-border technological spillover or can ultimately be explained by trade relationships among these countries remains an interesting question for future research.

4.4. Distribution of patent returns and patent designation

The estimates of μ_α and σ_α imply that in any specific country, pharmaceutical patents tend to have a higher median initial return and larger dispersion than electronics patents. These estimates are consistent with Lanjouw (1998)'s findings of a high pharmaceutical patent value based on a Germany sample, but in contrast to Schankerman (1998)'s French patent study that the pharmaceuticals are endowed with low median and mean returns and less dispersions than electronics.

As both authors have noted, France has the most stringent pharmaceutical price regulation and the lowest drug prices in Europe, whereas prices in Germany are largely unregulated and substantially higher than in many other west European countries. This may explain why Schankerman (1998) obtains a lower value estimate for pharmaceutical patents than electronics but Lanjouw (1998) has a higher estimate for pharmaceuticals. Such country differences in regulation policies are captured by our estimates of the country-fixed effects q_j's. Model estimates indicate that, on average, pharmaceutical patents have a substantially higher median return than electronics patents in most countries. The larger average family size of pharmaceutical patents (about 50% larger than electronics) also points to a higher value and explains why our results are in general consistent with Lanjouw (1998). Higher initial returns of pharmaceutical patents are also consistent with the distinction between discrete and complex technologies.

Table 4 displays the distribution of the simulated initial patent returns in each of the 10 EPO member countries in the two simulated patent groups. It reveals that, within the same technology group, the initial returns vary greatly across countries. For instance, the median of the initial returns of simulated pharmaceutical patents is $8610 (in 2000 U.S. dollars, same below) in Germany, $7650 in the U.K., but only $1430 in France, possibly reflecting the pharmaceutical price regulations in France. For electronics patents, the median of initial returns is $4080 in Germany, less than half of that of pharmaceutical patents in that country. The median initial returns of electronics patents are $2600 and $1770 in France and the U.K., respectively.

The draw of the initial returns from the distribution determines the patent applicants' designation decisions in different countries. As shown in Fig. 3, the simulated designation patterns match the data reasonably well for both patent groups. Almost all simulated pharmaceutical patents choose to designate Germany, France and the U.K. at the time of initial filing, and 96% choose to designate Italy. The designation rate for Luxembourg is 49%, the lowest among all EPO member countries. Corresponding to lower initial returns for the simulated electronics patents, their designation rate is also lower than pharmaceutical patents in almost all countries: almost 100% in Germany and France, 93% in the U.K., but only 58% in Italy. The average number of designated countries is 8.8 for the simulated pharmaceutical patents and 6.3 for the electronics patents, very close to the average number in the actual sample (8.3 for pharmaceutical and 5.6 for electronics patents as shown in Fig. 2).

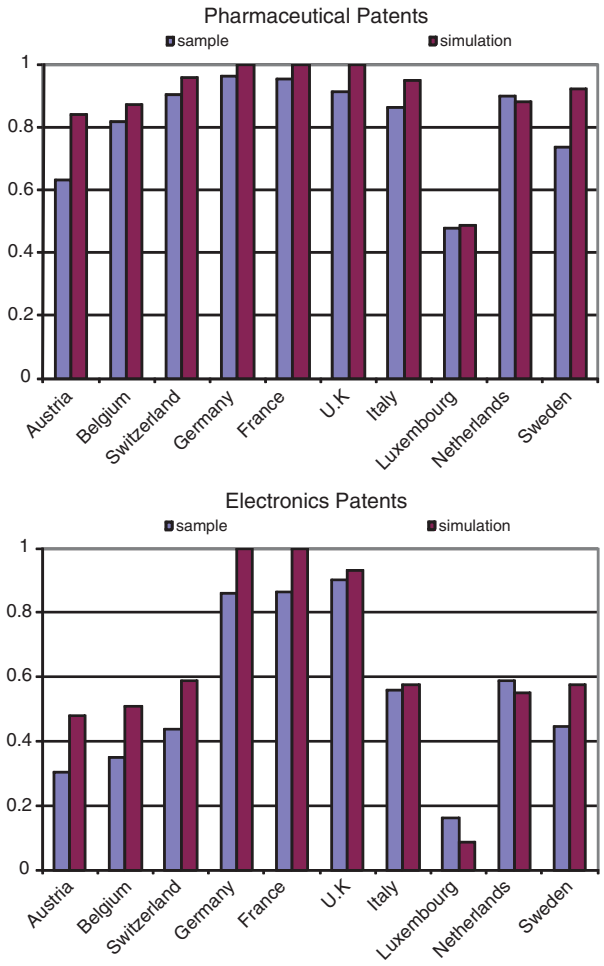

Fig. 3. Simulated and actual designation rates.

Table 4 also reveals that the distribution of the initial patent returns is highly skewed. For instance, in Germany, the sum of initial returns of the bottom 50% of pharmaceutical patents applications contributes about 0.6% of the total initial returns of the whole pharmaceutical group, and about 90% of the total initial returns are attributed to the top 10% of the patents. The bottom 50% of electronics patent applications contributes only 1% of the total initial returns of the whole group in Germany, while the top 10% contributes 85% of the total initial returns. The distribution of the initial returns in other countries has a similar pattern.

Table 5 compares the simulated value distribution of the patent families over their whole lives in these two technology fields, net of

Table 5
Distribution of the net value of simulated patents.

	Pharmaceutical		Electronics	
Percentile	Value ($ million)	LC	Value ($ million)	LC
50%	0.12	0.87	0.05	0.88
75%	0.57	4.74	0.22	4.79
90%	2.48	14.86	0.86	14.17
95%	5.68	25.37	1.91	23.38
99%	26.16	50.84	9.42	46.37
99.9%	142.77	78.17	60.86	71.67
Mean	1.79	–	0.70	–

Note: Columns 2 and 4 report the percentiles of the distribution of the total realized patent values in all 10 EPO member countries from the simulation. Columns 3 and 5 report the Lorenz curve coefficients of the simulated distribution. Monetary values are in units of 2000 U.S. dollars, and Lorenz curve coefficients (LC) are in percentage points.

designation and renewal costs. The median value of pharmaceutical patent families is about $0.12 million, more than twice as high as that of electronics patent families. The average value of pharmaceutical patent families is $1.79 million, again more than double that of electronics patents. On the other hand, the value distribution is highly skewed. For instance, the bottom 50% of low-valued pharmaceutical patent families accounts for less than 1% of the total value in the cohort, and the top 0.1% highly valued pharmaceutical patent families accounts for more than 20% of the total value. Such a highly skewed value distribution confirms Deng (2007)'s finding that "the owners of higher quality inventions not only choose to keep their patents alive longer in one country, but also seek patent protection in more countries."

4.5. Patent renewal decisions

Fig. 4 compares the renewal rate of the simulated patents in both technology groups, averaged across different destination countries and weighted by the number of patents transferred to each country. The simulated electronics patents have a significantly higher renewal rate at all ages and thus a longer average patent life, similar to the empirical renewal pattern displayed in Fig. 2. The median length of the simulated patent lives is 12 for pharmaceuticals and 14 for electronics, identical to the median life length as observed in the data (Fig. 2).

The obsolescence and depreciation dynamics play a very important role in the evolution of patent value over time and consequently in the patent holders' renewal decision making. The high obsolescence rate in pharmaceutical patents may reflect several characteristics of this industry. For instance, many of the pharmaceutical patents have to obtain approvals from certain food or drug administrations before entering the market, and the higher obsolescence rate may simply reflect the fact that a certain portion of them will not be able to pass the check and drop out. Alternatively, the different obsolescence rates of these two technology groups may also come from different characteristics of technological competitions in these two fields. As discussed above, pharmaceutical patents are often based on "discrete" technologies which are more likely to be exclusively utilized in the production of the final products such as drugs. Drugs treating the same diseases are substitutes: when a new drug is introduced, it quickly becomes a competitor to the existing ones and erodes their market shares. As a result, once a new patent is born in the same area, the old pharmaceutical patent may simply lose its value and becomes obsolete. By contrast, new technologies in electronics industries are often the results of some successive technological innovation process ("complex" technologies), and the patent owners often profit from the patented ideas through cross-licensing agreements. As Levin et al. (1987) point out, a firm's bargaining power in negotiating cross-licensing agreements depends on the relative size of its patent portfolio. Thus, electronics patent owners would have a strong incentive to maintain the size of their patent portfolios, because under asymmetric information this would strengthen their bargaining power. As the quality of patents in the portfolio is heterogeneous, some low-quality or "lemon" patents become unworthy for renewal at some point. However at the equilibrium the owner of the patent portfolio may still choose to "over renew" these "lemon" patents, as doing so will increase the size of his patent portfolio and subsequently increase his bargaining power. Thus the average renewal rate of electronics patents would tend to be higher, *ceteris paribus*.

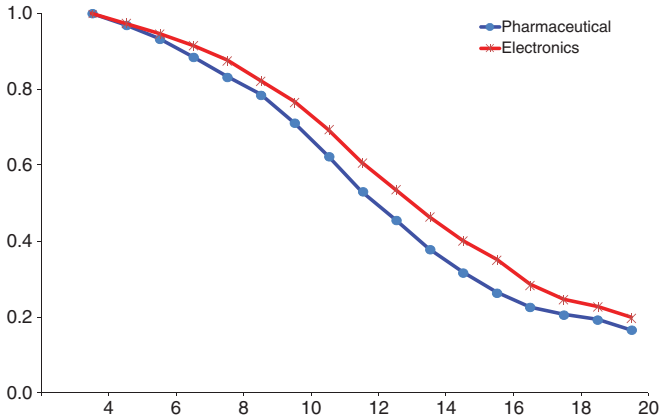

Fig. 4. Average renewal rates of the simulated patents.

5. Concluding remarks

This paper formulates a dynamic stochastic model to examine the joint patent application and renewal behaviors under an international patent-protection regime. The model utilizes both cross-sectional (multi-country application) and time-series (patent renewal) dimensions of international patenting data to evaluate the private value of patents in a unified structural framework, allowing us to examine the correlations between the patent family size and the length of patent life, and advancing our understanding of how the patent value changes over time as well as across different countries.

The model is estimated using the designation and renewal records of pharmaceutical and electronics patent applications filed with the European Patent Office from 1980 to 1985. Estimation results suggest that pharmaceutical innovations on average are endowed with higher initial returns, and the patent applicants seek protection in more countries than the electronics patent applicants. However, pharmaceutical patents become obsolete at a much faster pace than electronics patents, and consequently they have lower renewal rates and shorter lives. We also find that patent values in different countries are highly correlated with the market size of the country, and patents in these two technology fields have different returns to scale. In addition, compared with the national patents studied in previous literature, inventions filed with the EPO have a much longer learning process of their own values.

Appendix A. Model solution

Part I of Appendix A, based on the solution algorithm developed in Pakes (1986) and Lanjouw (1998), solves the renewal problem faced by the representative patentee in any member country j, $j=1,\ldots,J$. Part II extends the stochastic renewal model by Pakes (1986) to a multi-country setting and characterizes the representative patent applicant's application and designation decision rules and gives the estimator's moment conditions.

A.1. Part I. The renewal decision rule

The value of the patent at age t, as rewritten in Eq. (A1), is:

$$V(t,r_t) = \max\{0, r_t + \beta E_t V(t+1, r_{t+1}) - c_t\}. \quad \text{(A1)}$$

Starting from age T, the value function is given by:

$$V(T,r_T) = \max\{0, r_T - c_T\}. \quad \text{(A2)}$$

This is because T is the maximal age that the patent can possibly be kept in force and $E_T V(T+1, r_{T+1})$ is simply zero. The minimal return r_T^* to justify the renewal at age T can be obtained by setting Eq. (A2) to zero: $V(T, r_T)=0$, or $r_T^* = c_T$.

EXHIBIT 78

REDACTED IN ITS ENTIRETY

EXHIBIT 79

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Research Policy 29 (2000) 559–566

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Technology policy for a world of skew-distributed outcomes

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Abstract

This paper draws implications for technology policy from evidence on the size distribution of returns from eight sets of data on inventions and innovations attributable to private sector firms and universities. The distributions are all highly skew; the top 10% of sample members captured from 48 to 93 percent of total sample returns. It follows that programs seeking to advance technology should not be judged negatively if they lead to numerous economic failures; rather, emphasis should be placed on the relatively few big successes. To achieve noteworthy success with appreciable confidence, a sizeable array of projects must often be supported. The outcome distributions are sufficiently skewed that, even with large numbers of projects, it is not possible to diversify away substantial residual variability through portfolio strategies.

Keywords: Innovation; Risk; Skewness; Portfolio strategies

During the past several years the authors have been compiling data on the size distribution of financial returns within samples of significant technological innovations. Our uniform finding is that the returns are skew-distributed. Most innovations yield modest returns, but the size distribution has a long thin tail encompassing a relatively few innovations with particularly high returns. In this paper, we review earlier research, summarize our new evidence, and suggest implications for technology policy.

1. Prior research

Until recently there has been relatively little systematic empirical research on the statistical distribution properties of the returns from invention and innovation. Drawing upon a small sample survey of US patents, co-author Scherer (1965) (p. 1098) discovered a distribution of estimated profits from patented inventions so skew that ''patent statistics are likely to measure run-of-the-mill industrial inventive output much more accurately than they reflect the occasional strategic inventions which open up new markets and new technologies. The latter must probably remain the domain of economic historians.'' A second line of investigation differentiated the value of patents by the time when their holders chose not to pay the annual renewal fees imposed in some nations. The pioneering article in this tradition, overlooked by subsequent investigators, was by Dernburg and Gharrity (1961–1962). Leading examples of later investigations using more powerful econometric techniques include Pakes and Schankerman (1984), Pakes (1986), Schankerman and Pakes (1986), and

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0048-7333/00/$ - see front matter
PII: S0048-7333(99)00089-X

Lanjou et al. (1996). These studies confirmed that the size distribution of patent values is indeed quite skew, most likely conforming either to a log normal or Paretian distribution law. A third line of research by Grabowski and Vernon (1990; 1994) used the particularly rich data available on sales of individual ethical drugs throughout the world to estimate the distribution of profits (or more exactly, quasi-rents) attained by samples of new drugs approved by the US Food and Drug Administration (FDA). Again, a skew distribution was found, leading inter alia to the conclusion that heavy-handed price controls could jeopardize the continued vitality of new drug discovery and testing efforts (see e.g., Grabowski and Vernon, 1996; Scherer, 1996).

2. The new evidence

Altogether, we have assembled eight data sets, seven of which are new to the literature. Table 1 describes the samples and provides a simple indicator of distribution skewness — the fraction of total sample profits, royalties, or stock market value contributed by the 10% of the sample members realizing the highest absolute or relative rewards.

In the most ambitious of our efforts, we collected survey and interview evidence on 772 German- and 222 US-origin inventions, on all of which German patent applications were filed in 1977, leading to issued German patents considered sufficiently valuable by their holders to warrant paying annual renewal fees totalling DM 16,075 until their expiration at full term in 1995. These are called the ''German patents'' and ''US patents'' in Table 1.[1] Fig. 1 shows the distribution of summed German patent values by value class intervals, with the number of patents in each value category given in parentheses above the bars. Fifty-four percent of the value is concentrated in the five inventions with values of DM 50 million or more.

Table 1
Proportion of innovation samples' total value realized by the most valuable 10% of innovations

Data set	Number of observations	Percent of value in top 10%
German patents	772	84
US patents	222	81–85
Harvard patents	118	84
Six university patents		
1991 royalties	350	93
1992 royalties	408	92
1993 royalties	466	91.5
1994 royalties	411	92
Venture Economics startups	383	62
Horseley–Keogh startups	670	59
Initial public stock offerings (IPOs) — 1995 stock value	110	62
Grabowski–Vernon		
1970s drugs	98	55
1980s drugs	66	48

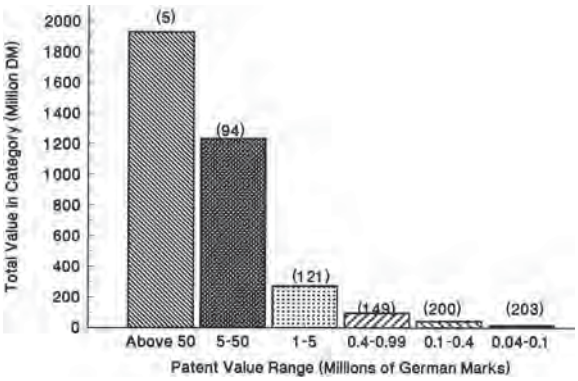

Fig. 1. Distribution of German patent values.

Our first-stage patent survey methodology asked company respondents to answer a single counterfactual question, phrased as follows in the US survey.

> If in 1980 you knew what you now know about the profit history of the invention abstracted here, what is the *smallest* amount for which you would have been willing to sell this patent to an independent third party, assuming that you had a bona fide offer to purchase and that the buyer would subsequently exercise its full patent rights?

In the first-stage survey, respondents were asked to place each sample patent in one of five value cate-

[1] A detailed analysis is found in Harhoff et al. (1997). The monetary patent value estimates are linked to subsequent patent citations in Harhoff et al. (1999).

EXHIBITS 80 - 83

REDACTED IN THEIR ENTIRETY

EXHIBIT 84

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

ST. JUDE MEDICAL, CARDIOLOGY DIVISION, INC., ST. JUDE MEDICAL SYSTEMS AB, and ST. JUDE MEDICAL S.C., INC., Plaintiff, v. VOLCANO CORPORATION, Defendant.	C.A. No. 10-631-RGA PUBLIC VERSION [redacted]

PARTIES' JOINT PROPOSED FINAL PRETRIAL ORDER – VOLCANO TRIAL

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Dated: September 25, 2012

IN THE UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF DELAWARE

ST. JUDE MEDICAL, CARDIOLOGY DIVISION, INC., ST. JUDE MEDICAL SYSTEMS AB, and ST. JUDE MEDICAL S.C., INC., Plaintiffs and Counterclaim Defendants, v. VOLCANO CORPORATION, Defendant and Counterclaimant.	Case No. 1:10-cv-00631-RGA **CONFIDENTIAL** **FILED UNDER SEAL**

TAB 11
JOINT BRIEFING ON VOLCANO'S MOTIONS *IN LIMINE*

conduct in Europe when faced with a similar rejection for lack of a description of this feature in the identical European patent (EP 1,658,808), and Volcano's own concession that this feature was lacking in the specification. Volcano argues that the legal standards in foreign countries are different from the United States, but whether its patent's written description describes the "lumen projecting into a housing feature" is a question of fact, not law. *See Centocor Ortho Biotech, Inc. v. Abbott Labs.*, 636 F.3d 1341, 1347 (Fed. Cir. 2011) ("Compliance with the written description requirement of 35 U.S.C. § 112, ¶ 1 is a question of fact."). Thus, Volcano's cases regarding legal determinations made in other jurisdictions are entirely irrelevant. Indeed, the Federal Circuit has endorsed relying on statements made in foreign prosecution histories where factual questions concerning the doctrine of equivalents were involved, *Tanabe Seiyaku Co. v. Int'l Trade Comm'n*, 109 F.3d 726, 733 (Fed. Cir. 1997) ("In evaluating infringement under the doctrine of equivalents, representation[s] to foreign patent offices should be considered ... when [they] comprise relevant evidence."), and there is no reason why factual questions concerning written description should be treated differently.

Volcano's response in the European prosecution is an admission, not a foreign legal determination. In responding to the examiner's rejection, Volcano ignored the examiner's point that there was no disclosure of a pressure sensitive region that projects into the lumen. (D.I. 285 Ex. 16, ¶ 588 (quoting Volcano's Response).) The examiner maintained his rejection and pointed out that Volcano's response was nonresponsive. (*Id.* ¶ 589.) Volcano then abandoned its application for these claims, which are identical to the '965 Patent Claim 1 that Volcano is asserting against St. Jude. (*Id.* ¶ 569.) Volcano's acquiescence in the examiner's rejection is an admission against interest demonstrating that Volcano itself recognized that its specification does not describe a pressure sensitive region that projects into the lumen of the sensor housing.

C. VOLCANO'S REPLY

Radi's '442 patent cannot provide evidence of "separate patentability." First, Volcano's '856 patent was not cited or considered during prosecution of Radi's '442 patent. Second, none of the claims of the '442 patent is directed to the "sleeveless gap-and-separate-chamfer-wire male connector" St. Jude contends distinguish its products from the '159 or '856 patents.[9] Third, the single dependent claim of the '442 patent that references a "separate" core wire (claim 20) was deemed patentable based on the many limitation of its base claim. Indeed, Volcano's '159 patent teaches a two-piece core wire, meaning this feature alone could not be inventive more than a decade later. [*See* D.I. 275 Ex. 20 Figs. 1, 3-5.] St. Jude concedes the '442 patent is irrelevant to literal infringement. Because a two-piece core wire could not be the basis of patentability, it is also irrelevant to DOE. As such, the '442 patent should be excluded because its introduction would only complicate Volcano's trial, confuse the jury and prejudice Volcano.

The'808 application will likewise prove confusing to the jury, as its introduction will require the Court and the parties to explain the different legal standards applied in foreign and U.S. patent prosecution practice. The parties will also be required to address the prosecution history of the '808 foreign application and St. Jude's mistaken characterization of it. Moreover, far from providing evidence of an affirmative party "statement" or "admission against interest," the foreign prosecution history at most constitutes a determination by a foreign patent ***examiner***, which he subsequently withdrew. Given the absence of probative evidence and the great deal of time that will need to be expended to address these extraneous issues, the EP 808 patent and its prosecution should also be excluded from both trials.

[9] Although Dr. Durfee compared St. Jude's accused products and the '442 patent, he never opined that those accused products embody the '442 patent.

V. VOLCANO'S MOTION *IN LIMINE* #5: TO EXCLUDE REFERENCE TO THE EXPIRATION DATE OF U.S. PATENT NO. 5,178,159

A. VOLCANO'S OPENING STATEMENT

Volcano respectfully requests that the Court preclude St. Jude during both trials from presenting any evidence regarding the expiration date of U.S. Patent No. 5,178,159 ("the '159 patent"), or from otherwise informing the jury that the '159 patent has expired. The expiration of the '159 patent is only relevant, if at all, to the issue of damages due to Volcano, which has been bifurcated from the upcoming jury trial. Because the jury might mistakenly believe that an expired patent cannot be infringed prior to its expiration or that, that it cannot serve as invalidating prior art to St. Jude's asserted '624 and '980 patents, or that the '159 patent is somehow weaker on the merits than the other patents, allowing such evidence to be considered would be substantially more prejudicial than probative. *See* Fed. R. Evid. 402 & 403.

The sole issues for the jury in the October trials are whether the asserted patents are infringed and/or valid. Neither of these inquiries depends on or in any way relates to the recent expiration of the '159 patent. The only St. Jude products accused of infringing the '159 patent were made, used, offered for sale, or sold prior to the expiration of the '159 patent. *See* D.I. 275 Ex. 27 Expert Report of Jerome Segal at ¶¶ 41-47, 52. Specifically, Volcano is accusing St. Jude's PressureWire products, model numbers 12000-12002, 12003/12303, 12004/12304, 12005/12305, and 12006/12306 of infringing the '159 patent. *Id.* All of these accused products received marketing approval from the Food and Drug Administration ("FDA") on or before December 4, 2006, and were launched in or before 2008. *See id.*; *see also* Ex. 3 (Deposition of Stefan Tiensuu, Ex. 2). Although St. Jude may have sold some of these products after expiration, the specific time periods during which those products were sold is not relevant to the infringement and validity issues being considered by the jury. Instead, if the jury finds that these

EXHIBIT 85

REDACTED IN ITS ENTIRETY

EXHIBIT 86

United States Patent [19]

Palmaz

[11] **Patent Number: 4,733,665**

[45] **Date of Patent: Mar. 29, 1988**

[54] **EXPANDABLE INTRALUMINAL GRAFT, AND METHOD AND APPARATUS FOR IMPLANTING AN EXPANDABLE INTRALUMINAL GRAFT**

[75] Inventor: **Julio C. Palmaz**, San Antonio, Tex.

[73] Assignee: **Expandable Grafts Partnership**, San Antonio, Tex.

[21] Appl. No.: **796,009**

[22] Filed: **Nov. 7, 1985**

[51] **Int. Cl.**[4] **A61M 29/00**

[52] **U.S. Cl.** **128/343**; 604/104; 604/96; 623/1

[58] **Field of Search** ..... 128/343–344, 128/1 R; 623/1; 604/96, 104, 106–109

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Primary Examiner—C. Fred Rosenbaum
Assistant Examiner—Gene B. Kartchner
Attorney, Agent, or Firm—Ben D. Tobor

[57] **ABSTRACT**

An expandable intraluminal vascular graft is expanded within a blood vessel by an angioplasty balloon associated with a catheter to dilate and expand the lumen of a blood vessel. The graft may be a wire mesh tube.

28 Claims, 6 Drawing Figures

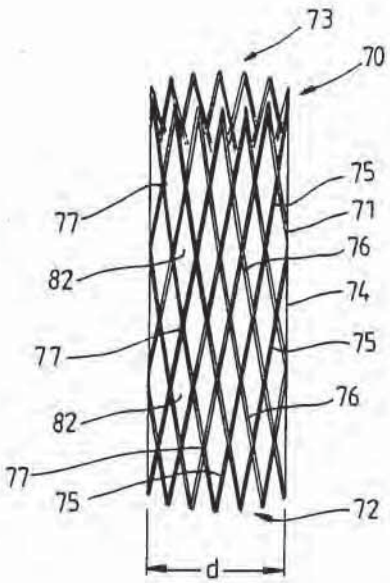


Fig. 1A

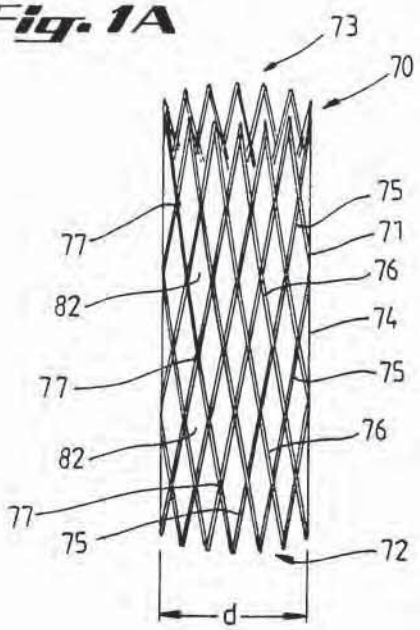


Fig. 1B

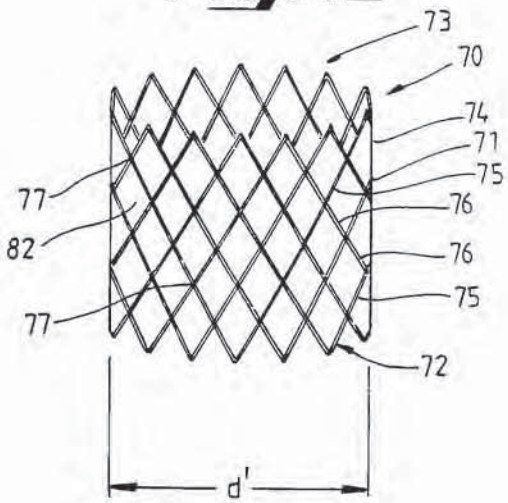


Fig. 2A

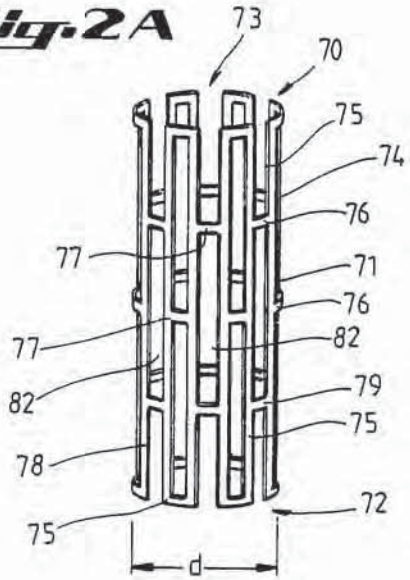


Fig. 2B

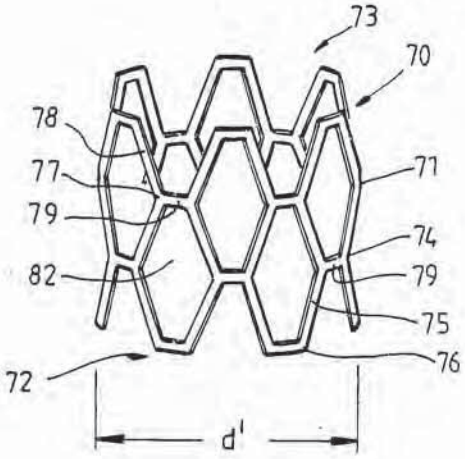
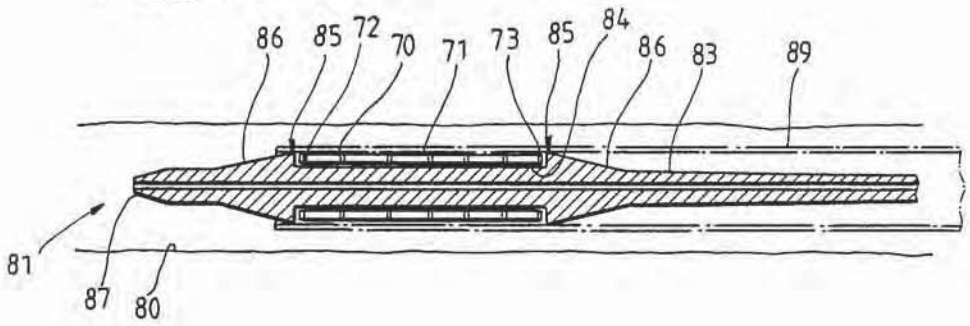


Fig. 3



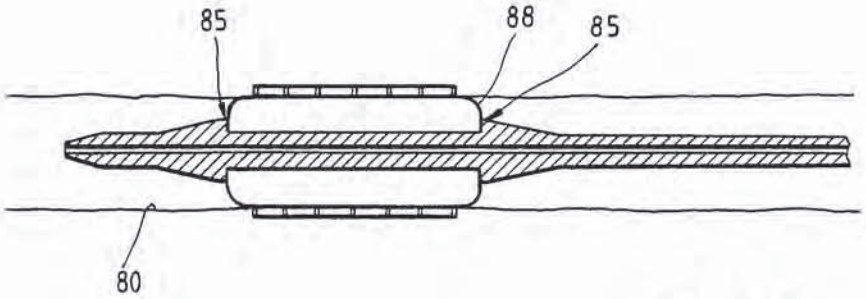


Fig. 4

EXPANDABLE INTRALUMINAL GRAFT, AND METHOD AND APPARATUS FOR IMPLANTING AN EXPANDABLE INTRALUMINAL GRAFT

Field of the Invention

The government of the United States of America retains a non-exclusive, irrevocable, royalty-free license in this invention for all governmental purposes, pursuant to 37 C.F.R. §100.6(b) (2).

The invention relates to an expandable intraluminal graft for use within a body passageway or duct and, more particularly, expandable intraluminal vascular grafts which are particularly useful for repairing blood vessels narrowed or occluded by disease; and a method and apparatus for implanting expandable intraluminal grafts.

Description of the Prior Art

Intraluminal endovascular grafting has been demonstrated by experimentation to present a possible alternative to conventional vascular surgery. Intraluminal endovascular grafting involves the percutaneous insertion into a blood vessel of a tubular prosthetic graft and its delivery via a catheter to the desired location within the vascular system. Advantages of this method over conventional vascular surgery include obviating the need for surgically exposing, incising, removing, replacing, or bypassing the defective blood vessel.

Structures which have previously been used as intraluminal vascular grafts have included coiled stainless steel springs; helically wound coil springs manufactured from an expandable heat-sensitive material; and expanding stainless steel stents formed of stainless steel wire in a zig-zag pattern. In general, the foregoing structures have one major disadvantage in common. Insofar as these structures must be delivered to the desired location within a given body passageway in a collapsed state, in order to pass through the body passageway, there is no effective control over the final, expanded configuration of each structure. For example, the expanison of a particular coiled spring-type graft is predetermined by the spring constant and modulus of elasticity of the particular material utilized to manufacture the coiled spring structure. These same factors predetermine the amount of expansion of collapsed stents formed of stainless steel wire in a zig-zag pattern. In the case of intraluminal grafts, or prostheses, formed of a heat sensitive material which expands upon heating, the amount of expansion is likewise predetermined by the heat expansion characteristics of the particular alloy utilized in the manufacture of the intraluminal graft.

Thus, once the foregoing types of intraluminal grafts are expanded at the desired location within a body passageway, such as within an artery or vein, the expanded size of the graft cannot be changed. If the diameter of the desired body passageway has been miscalculated, an undesized graft might not expand enough to contact the interior surface of the body passageway, so as to be secured thereto. It may then migrate away from the desired location within the body passageway. Likewise, an oversized graft might expand to such an extent that the spring force, or expansion force, exerted by the graft upon the body passageway could cause rupturing of the body passageway.

Another alternative to conventional vascular surgery has been percutaneous balloon dilation of elastic vascular stenoses, or blockages, through use of a catheter

mounted angioplasty balloon. In this procedure, the angioplasty balloon is inflated within the stenosed vessel, or body passageway, in order to shear and disrupt the wall components of the vessel to obtain an enlarged lumen. With respect to arterial atheroscleerotic lesions, the relatively incompressible plaque remains unaltered, while the more elastic medial and adventitial layers of the body passageway stretch around the plaque. This process produces dissection, or a splitting and tearing, of the body passageway wall layers, wherein the intima, or internal surface of the artery or body passageway, suffers fissuring. This dissection forms a "flap" of underlying tissue which may reduce the blood flow through the lumen, or block the lumen. Typically, the distending intraluminal pressure within the body passageway can hold the disrupted layer, or flap, in place. If the intimal flap created by the balloon dilation procedure is not maintained in place against the expanded intima, the intimal flap can fold down into the lumen and close off the lumen, or may even become detached and enter the body passageway. When the intimal flap closes off the body passageway, immediate surgery is necessary to correct this problem.

Although the balloon dilation procedure is typically conducted in the catheterization lab of a hospital, because of the foregoing problem, it is always necessary to have a surgeon on call should the intimal flap block the blood vessel or body passageway. Further, because of the possibility of the intimal flap tearing away from the blood vessel and blocking the lumen, balloon dilations cannot be performed upon certain critical body passageways, such as the left main coronary artery, which leads into the heart. If an intimal flap formed by a balloon dilation procedure abruptly comes down and closes off a critical body passageway, such as the left main coronary artery, the patient could die before any surgical procedures could be performed.

Additional disadvantages associated with balloon dilation of elastic vascular stenoses is that many fail because of elastic recoil of the stenotic lesion. This usually occurs due to a high fibrocollagenous content in the lesion and is sometimes due to certain mechanical characteristics of the area to be dilated. Thus, although the body passageway may initially be successfully expanded by a balloon dilation procedure, subsequent, early restenosis can occur due to the recoil of the body passageway wall which decreases the size of the previously expanded lumen of the body passageway. For example, stenoses of the renal artery at the ostium are known to be refractory to balloon dilation because the dilating forces are applied to the aortic wall rather than to the renal artery itself. Vascular stenoses caused by neointimal fibrosis, such as those seen in dialysis-access fistulas, have proved to be difficult to dilate, requiring high dilating pressures and larger balloon diameters. Similar difficulties have been observed in angioplasties of graft-artery anastomotic strictures and postendarterectomy recurrent stenoses. Percutaneous angioplasty of Takayasu arteritis and neurofibromatosis arterial stenoses may show poor initial response and recurrence which is believed due to the fibrotic nature of these lesions.

Accordingly, prior to the development of the present invention, there has been no expandable intraluminal vascular graft, and method and apparatus for expanding the lumen of a body passageway, which: prevents recurrence of stenoses in the body passageway; can be

utilized for critical body passageways, such as the left main coronary artery of a patient's heart; prevents recoil of the body passageway wall; and allows the intraluminal graft to be expanded to a variable size to prevent migration of the graft away from the desired location; and to prevent rupturing of the body passageway by the expanded graft. Therefore, the art has sought an expandable intraluminal vascular graft, and method and apparatus for expanding the lumen of a body passageway which: prevents recurrence of stenoses in the body passageway; is believed to be able to be utilized in critical body passageways, such as the left main coronary artery of the heart; prevents recoil of the body passageway; and can be expanded to a variable size within the body passageway to prevent migration of the graft away from the desired location; and to prevent rupturing of the body passageway by the expanded graft.

SUMMARY OF THE INVENTION

In accordance with the invention the foregoing advantages have been achieved through the present expandable intraluminal vascular graft. The present invention includes a tubular shaped member having first and second ends and a wall surface disposed between the first and second ends, the wall surface being formed by a plurality of intersecting elongate members, at least some of the elongate members intersecting with one another intermediate the first and second ends of the tubular shaped member; the tubular shaped member having a first diameter which permits intraluminal delivery of the tubular shaped member into a body passageway having a lumen; and the tubular shaped member having a second, expanded diameter, upon the application from the interior of the tubular shaped member of a radially, outwardly extending force, which second diameter is variable and dependent upon the amount of force applied to the tubular shaped member, whereby the tubular shaped member may be expanded to expand the lumen of the body passageway.

A further feature of the present invention is that the plurality of elongate members may be a plurality of wires, and the wires may be fixedly secured to one another where the wires intersect with one another. An additional feature of the present invention is that the plurality of elongate members may be a plurality of thin bars which are fixedly secured to one another where the bars intersect with one another. A further feature of the present invention is that the tubular shaped member may have a biologically inert coating on its wall surface, and the coating may include a means for anchoring the tubular shaped member to the body passageway.

In accordance with the invention, the foregoing advantages have also been achieved through the present method for expanding the lumen of a body passageway. The method of the present invention comprises the steps of: inserting an intraluminal graft, disposed upon a catheter, into the body passageway until it is disposed adjacent a desired location within the body passageway; and expanding a portion of the catheter to cause the intraluminal graft to radially expand outwardly into contact with the body passageway until the lumen of the body passageway at the desired location of the body passageway has been expanded, whereby the intraluminal graft prevents the body passageway from collapsing and decreasing the size of the expanded lumen.

A further feature of the present invention is that the portion of the catheter in contact with the intraluminal graft may be collapsed, and the catheter removed from the body passageway. A further feature of the present invention is that a catheter having an expandable, inflatable portion associated therewith may be utilized; and expansion of the intraluminal graft and the portion of the catheter is accomplished by inflating the expandable, inflatable portion of the catheter.

A further feature of the present invention is that a wire mesh tube may be utilized as the intraluminal graft, the wire mesh tube having a first predetermined, collapsed diameter which permits the tube to be inserted within the body passageway at and delivered to the desired location. Another feature of the present invention is that the wire mesh tube may be expanded to a second diameter within the body passageway; the second, expanded diameter being variable and determined by the desired expanded internal diameter of the body passageway, whereby the expanded wire mesh tube will not migrate from the desired location within the body passageway and the expansion of the intraluminal graft does not cause a rupture of the body passageway.

In accordance with the invention, the foregoing advantages have also been achieved through the present apparatus for intraluminally reinforcing a body passageway. The present invention includes: an expandable, tubular shaped prosthesis having first and second ends and a wall surface disposed between the first and second ends, the wall surface being formed by a plurality of intersecting elongate members; and a catheter, having an expandable, inflatable portion associated therewith and including means for mounting and retaining the expandable tubular shaped prosthesis on the expandable, inflatable portion, whereby upon inflation of the expandable, inflatable portion of the catheter, the prosthesis is forced radially into contact with the body passageway. A further feature of the present invention is that the mounting and retaining means may comprise a retainer ring member disposed on the catheter adjacent the expandable, inflatable portion and adjacent each end of the expandable, tubular shaped prosthesis.

The expandable intraluminal vascular graft, method for expanding the lumen of a body passageway, and apparatus for intraluminally reinforcing a body passageway of the present invention, when compared with previously proposed prior art intraluminal grafts, methods for implanting them, and balloon dilation techniques have the advantages of: preventing recurrence of stenoses; is believed to permit implantation of grafts in critical body passageways, such as in the left main coronary artery of the heart; prevents recoil of the body passageway; and permits expansion of the graft to a variable size dependent upon conditions within the body passageway.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1A is a perspective view of an expandable intraluminal vascular graft, or prosthesis for a body passageway, having a first diameter which permits delivery of the graft, or prosthesis, into a body passageway;

FIG. 1B is a perspective view of the graft, or prosthesis, of FIG. 1A, in its expanded configuration when disposed within a body passageway;

FIG. 2A is a perspective view of another embodiment of an expandable intraluminal vascular graft, or prosthesis for a body passageway, having a first diameter which permits intraluminal delivery of the graft, or prosthesis, into a body passageway;

FIG. 2B is a perspective view of the graft, or prosthesis, of FIG. 2A, shown in its expanded configuration when disposed within a body passageway;

FIG. 3 is a cross-sectional view of an apparatus for intraluminally reinforcing a body passageway, or for expanding the lumen of a body passageway, illustrating a prosthesis, or intraluminal vascular graft, in the configurations shown in FIGS. 1A and 2A;

FIG. 4 is a cross-sectional view of the apparatus for intraluminally reinforcing a body passageway, or for expanding the lumen of a body passageway, with a graft, or prosthesis, in the configurations shown in FIGS. 1B and 2B.

When the invention will be described in connection with the preferred embodiment, it will be understood that it is not intended to limit the invention to that embodiment. On the contrary, it is intended to cover all alternatives, modifications, and equivalents, as may be included within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

In FIGS. 1A and 2A, an expandable intraluminal vascular graft, or expandable prosthesis for a body passageway, 70 is illustrated. It should be understood that the terms "expandable intraluminal vascular graft" and "expandable prosthesis" are interchangeably used to some extent in describing the present invention, insofar as the methods, apparatus, and structures of the present invention may be utilized not only in connection with an expandable intraluminal vascular graft for expanding partially occluded segments of a blood vessel, or body passageway, but may also be utilized for many other purposes as an expandable prosthesis for many other types of body passageways. For example, expandable prostheses 70 may also be used for such purposes as: (1) supportive graft placement within blocked arteries opened by transluminal recanalization, but which are likely to collapse in the absence of an internal support; (2) similar use following catheter passage through mediastinal and other veins occluded by inoperable cancers; (3) reinforcement of catheter created intrahepatic communications between portal and hepatic veins in patients suffering from portal hypertension; (4) supportive graft placement of narrowing of the esophagus, the intestine, the ureters, the urethra; and (5) supportive graft reinforcement of reopened and previously obstructed bile ducts. Accordingly, use of the term "prosthesis" encompasses the foregoing usages within various types of body passageways, and the use of the term "intraluminal vascular graft" encompasses use for expanding the lumen of a body passageway. Further, in this regard, the term "body passageway" encompasses any duct within the human body, such as those previously described, as well as any vein, artery, or blood vessel within the human vascular system.

Still with reference to FIG. 1A, the expandable intraluminal vascular graft, or prosthesis, 70 is shown to generally comprise a tubular shaped member 71 having first and second ends 72, 73 and a wall surface 74 disposed between the first and second ends 72, 73. Preferably, the wall surface 74 is formed by a plurality of intersecting elongate members 75, 76 with at least some of the elongate members 75, 76 intersecting with one another intermediate the first and second ends 72, 73 of the tubular shaped member 71, such as shown at intersection points 77. Tubular shaped member 71 has a first diameter, d, which, to be hereinafter described in greater detail, permits intraluminal delivery of the tubular shaped member 71 into a body passageway 80 having a lumen (FIG. 3). With reference to FIG. 1B, upon the application from the interior of the tubular shaped member 71 of a radially, outwardly extending force, to be hereinafter described in greater detail, tubular shaped member 71 has a second, expanded diameter, d', which second diameter d' is variable in size and dependent upon the amount of force applied to the tubular shaped member 71.

With reference to FIGS. 1A and 1B, elongate members 75, 76, which form wall surface 74 of tubular shaped member 71, may be any suitable material which is compatible with the human body and the bodily fluids (not shown) with which the vascular graft, or prosthesis, 70 may come into contact. Elongate members 75, 76 must also be made of a material which has the requisite strength and elasticity characteristics to permit the tubular shaped member 71 to be expanded from the configuration shown in FIG. 1A to the configuration shown illustrated in FIG. 1B and further to permit the tubular shaped member 71 to retain its expanded configuration with the enlarged diameter d' shown in FIG. 1B. Suitable materials for the fabrication of tubular shaped member 71 would include silver, tantalum, stainless steel, gold, titanium or any suitable plastic material having the requisite characteristics previously described. Preferably, elongate members 75, 76 are fabricated from stainless steel. Preferably, the elongate members 75, 76 illustrated in FIGS. 1A and 1B are small diameter stainless steel wires having a cylindrical cross-section. It should of course be understood that each elongate member 75, 76, could have other cross-sectional configurations, such as triangular, square, rectangular, hexagonal, etc. Further, it is preferable that the plurality of elongate members 75, 76 are fixedly secured to one another where the elongate members 75, 76 intersect with one another, such as at the intersection points 77. Elongate members 75, 76 could be fixedly secured to one another in any conventional manner, such as by welding, soldering, or gluing, such as with a suitable epoxy glue; however, it is preferred that the intersection points 77 are soldered with silver. By fixedly securing the elongate members 75, 76, to one another, tubular member 71 is provided with a relatively high resistance to radial collapse, and the tubular shaped member 71 has the ability to retain its enlarged diameter, d', as shown in FIG. 1B. Preferably, tubular shaped member 71 is made of continuous, stainless steel wire woven in a criss-crossed tubular pattern to form what can be generally described as a wire mesh tube.

When fabricating tubular shaped member, or wire mesh tube, 71, it can be initially fabricated in the configuration shown in FIG. 1A with diameter, d. Alternatively, it can be fabricated with a diameter which is larger than initial diameter d and after fabrication, tubular shaped member 71 could be carefully collapsed to have diameter d shown in FIG. 1A. During the collapsing of tubular shaped member, or wire mesh tube, 71, care must be taken to insure that overlapping of adjacent elongate members 75, 76 is avoided. It should of course be understood that upon expansion of tubular shaped member, or wire mesh tube, 71 into the configuration shown in FIG. 1B, the distance between first and second ends 72 and 73 will of course decrease.

With reference now to FIGS. 2A and 2B, another embodiment of expandable intraluminal vascular graft,

or prosthesis, 70, is illustrated. The same reference numerals are utilized and are applicable for elements previously described in FIGS. 1A and 1B. The intraluminal vascular graft, or prosthesis, 70 of FIGS. 2A and 2B differs from that previously described in connection with FIGS. 1A and 1B, in that the plurality of elongate members 75 and 76 are a plurality of thin bars 78, 79 which are preferably fixedly secured to one another where the bars 78, 79 intersect with one another. Bars 78, 79 preferably have a thin, rectangular cross-sectional configuration, and may be joined to one another in any conventional manner, such as by welding, brazing, soldering, or may be formed integral with one another. Preferably, tubular shaped member 71 is initially a thin-walled stainless steel tube, and the openings 82 between the intersecting bars 78 and 79 are formed by a conventional etching process, such as electromechanical or laser etching, whereby the resultant structure is a tubular shaped member 71 having a plurality of intersecting elongate members 78, 79. The embodiment of graft, or prosthesis, 70 of FIG. 2A, likewise can assume an expanded configuration as shown in FIG. 2B and as previously described in connection with FIG. 1B, upon the application from the interior of the tubular shaped member 71 of a radially, outwardly extending force. It should be further understood that the embodiment of vascular graft, or prosthesis, 70 of FIGS. 2A and 2B, could also be generally described as a wire mesh tube.

With reference now to FIGS. 3 and 4, the methods and apparatus of the present invention will be described in greater detail. Once again, it should be understood that the methods and apparatus of the present invention are useful not only for expanding the lumen of a body passageway, such as an artery, vein, or blood vessel of the human vascular system, but are also useful to perform the previously described procedures to intraluminally reinforce other body passageways or ducts, as previously described. Still with reference to FIGS. 3 and 4, an expandable intraluminal vascular graft, or prosthesis, 70, which may be of the type previously described in connection with FIGS. 1A or 2A, is disposed or mounted upon a catheter 83. Catheter 83 has an expandable, inflatable portion 84 associated therewith. Catheter 83 includes means for mounting and retaining 85 the expandable intraluminal vascular graft, or prosthesis, 70 on the expandable, inflatable portion 84 of catheter 83. Preferably, the mounting and retaining means 85 comprises retainer ring members 86 disposed on the catheter 83 adjacent the expandable inflatable portion 84 of catheter 83; and a retainer ring member 86 is disposed adjacent each end 72, 73 of the expandable intraluminal vascular graft, or prosthesis, 70. Preferably, as seen in FIG. 3, while retainer ring members are formed integral with catheter 83, and the retainer ring member 86 adjacent the leading tip 87 of catheter 83 slopes upwardly and away from catheter tip 87 in order to protect and retain graft or prosthesis, 70 as it is inserted into the lumen 81 of body passageway 80, as to be hereinafter described in greater detail. The remaining retainer ring member 86 as shown in FIG. 3, slopes downwardly away from tip 87 of catheter 83, to insure easy removal of catheter 83 from body passageway 80. After expandable intraluminal graft, or prosthesis, 70 has been disposed upon catheter 83, in the manner previously described, the graft, or prosthesis, 70 and catheter 83 are inserted within a body passageway 80 by catheterization of the body passageway 80 in a conventional manner.

In a conventional manner, the catheter 83 and graft, or prosthesis, 70 are delivered to the desired location within the body passageway 80, whereat it is desired to expand the lumen 81 of body passageway 80 via intraluminal graft 70, or where it is desired to implant prosthesis 70. Fluoroscopy, and/or other conventional techniques may be utilized to insure that the catheter 83 and graft, or prosthesis, 70 are delivered to the desired location within the body passageway. Prosthesis, or graft, 70 are then expanded by expanding the expandable, inflatable portion 84 of catheter 83, whereby the prosthesis, or graft, 70 is forced radially, outwardly into contact with the body passageway 80 as shown, in FIG. 4. In this regard, the expandable, inflatable portion of catheter 83 may be a conventional angioplasty balloon 88. After the desired expansion of prosthesis, or graft, 70 has been accomplished, angioplasty balloon 88 may be collapsed, or deflated, and the catheter 83 may be removed in a conventional manner from body passageway 80. If desired, as seen in FIG. 3, catheter 83, having graft or prosthesis, 70 disposed thereon, may be initially encased in a conventional Teflon TM sheath 89, which is pulled away from prosthesis, or graft, 70, prior to expansion of the prosthesis, or graft, 70.

Still with reference to FIGS. 3 and 4, it should be noted that the tubular shaped member 71 of prosthesis, or graft, 70 initially has the first predetermined, collapsed diameter d as described in connection with FIGS. 1A and 2A, in order to permit the insertion of the wire mesh tube, or tubular shaped member, 71 into the body passageway 80 as previously described. When it is desired to implant prosthesis 70 within a body passageway 80 for the purposes previously described, the wire mesh tube, or prosthesis 70, is expanded to the second diameter d' and the second, expanded diameter d' is variable and determined by the internal diameter of the body passageway 80, as shown in FIG. 4. Accordingly, the expanded prosthesis 70, upon deflation of angioplasty balloon 88 will not be able to migrate from the desired location within the body passageway 80, nor will the expansion of the prosthesis 70 be likely to cause a rupture of the body passageway 80.

When it is desired to use expandable intraluminal graft 70 to expand the lumen 81 of a body passageway 80 having an area of stenosis, the expansion of intraluminal vascular graft 70 by angioplasty balloon 88, allows controlled dilation of the stenotic area and, at the same time controlled expansion of the vascular graft 70, whereby vascular graft 70 prevents the body passageway 80 from collapsing and decreasing the size of the previously expanded lumen 81. Once again, the second, expanded diameter d' of intraluminal vascular graft 70, as shown in FIG. 4 is variable and determined by the desired expanded internal diameter of body passageway 80. Thus, the expandable intraluminal graft 70 will not migrate away from the desired location within the body passageway 80 upon deflation of angioplasty balloon 88, nor will the expansion of intraluminal graft 70 likely cause a rupture of body passageway 80. Further, should an intimal flap, or fissure, be formed in body passageway 80 at the location of graft 70, graft 70 will insure that such an intimal flap will not be able to fold inwardly into body passageway 80, nor tear loose and flow through body passageway 80. In the situation of utilizing graft 70 in the manner previously described to expand the lumen of a portion of the left main artery, it is believed that the intimal flap will be unable to enter the heart and cause the death of the patient.

Because it is only necessary to inflate angioplasty balloon **88** one time in order to expand graft **70**, it is believed that a greater amount of endothelium, or inner layer of the intima, or inner surface of the body passageway, will be preserved, insofar as the extent of endothelial denudation during transluminal angioplasty is proportional to the balloon inflation time. Further, in theory, the amount of preserved endothelium should be large because in the expanded configuration of graft **70**, potentially 80% of the endothelium is exposed through openings **82** of graft **70**. It is further believed that intact patches of endothelium between the elongate members **75, 76, 78, 79** of graft **70** may result in a rapid, multicentric endothelialization pattern as shown by experimental studies.

It is to be understood that the invention is not limited to the exact details of construction, operation, exact materials or embodiment shown and described, as obvious modifications and equivalents will be apparent to one skilled in the art. For example, the means for expanding the prosthesis or graft could be a plurality of hydraulically actuated rigid members disposed on a catheter, or a plurality of angioplasty balloons could be utilized to expand the prosthesis or graft. Accordingly, the invention is therefore to be limited only by the scope of the appended claims.

What is claimed is:

1. A method for implanting a prosthesis within a body passageway comprising the steps of:

disposing the prosthesis upon a catheter;

inserting the prosthesis and catheter within the body passageway by catheterization of said body passageway; and

providing controllable expansion of the prosthesis at a desired location within the body passageway by expanding a portion of the catheter associated with the prosthesis to force the prosthesis radially outwardly into contact with the body passageway, by deforming a portion of the prosthesis with a force in excess of the elastic limit of the portion of the prosthesis, to implant the prosthesis within the body passageway.

2. The method of claim **1**, further including the steps of: collapsing the portion of the catheter associated with the prosthesis, and removing the catheter from the body passageway.

3. The method of claim **1**, including the steps of: utilizing a catheter having an expandable, inflatable portion associated therewith; and the controllable expansion of the prosthesis and the portion of the catheter is accomplished by inflating the expandable, inflatable portion of the catheter.

4. The method of claim **1**, including the step of: utilizing a wire mesh tube as the prosthesis, the wire mesh tube having a first predetermined collapsed diameter which permits the tube to be disposed upon the catheter and inserted into the body passageway.

5. The method of claim **4**, wherein tantalum is utilized for the wire mesh tube.

6. The method of claim **4**, wherein the wire mesh tube is expanded to a second diameter within the body passageway; the second, expanded diameter being variable and determined by the internal diameter of the body passageway, whereby the expanded wire mesh tube will not migrate from the desired location within the body passageway and the expansion of the prosthesis does not cause a rupture of the body passageway.

7. A method for expanding the lumen of a body passageway comprising the steps of:

inserting an intraluminal graft, disposed upon a catheter, into the body passageway until it is disposed adjacent a desired location within the body passageway; and

expanding a portion of the catheter to provide controllable expansion of the intraluminal graft radially, outwardly into contact with the body passageway, by deforming a portion of the intraluminal graft with a force in excess of the elastic limit of the portion of the prosthesis, until the lumen of the body passageway at the desired location in the body passageway has been expanded, whereby the intraluminal graft prevents the body passageway from collapsing and decreasing the size of the expanded lumen, and the intraluminal graft remains in the passageway.

8. The method of claim **7**, further including the steps of: collapsing the portion of the catheter in contact with the intraluminal graft and removing the catheter from the body passageway.

9. The method of claim **7**, including the steps of: utilizing a catheter having an expandable, inflatable portion associated therewith; and the controllable expansion of the intraluminal graft and the portion of the catheter is accomplished by inflating the expandable, inflatable portion of the catheter.

10. The method of claim **7**, including the step of: utilizing a wire mesh tube as the intraluminal graft, the wire mesh tube having a first predetermined, collapsed diameter which permits the tube to be inserted within the body passageway at the desired location.

11. The method of claim **10**, wherein tantalum is utilized for the wire mesh tube.

12. The method of claim **10**, wherein the wire mesh tube is expanded to a second diameter within the body passageway; the second, expanded diameter being variable and determined by the desired expanded internal diameter of the body passageway, whereby the expanded wire mesh tube will not migrate from the desired location within the body passageway and the expansion of the intraluminal graft does not cause a rupture of the body passageway.

13. An expandable intraluminal vascular graft, comprising:

a tubular shaped member having first and second ends and a wall surface disposed between the first and second ends, the wall surface being formed by a plurality of intersecting elongate members, at least some of the elongate members intersecting with one another intermediate the first and second ends of the tubular shaped member;

the tubular shaped member having a first diameter which permits intraluminal delivery of the tubular shaped member into a body passageway having a lumen; and

the tubular shaped member having a second, expanded diameter, upon the application from the interior of the tubular shaped member of a radially, outwardly extending force, which second diameter is variable and controlled by the amount of force applied to the tubular shaped member, at least some of the elongate members being deformed by the radially, outwardly extending force, to retain the tubular shaped member with the second, expanded diameter, whereby the tubular shaped member may

be expanded to expand the lumen of the body passageway and remain therein.

14. The expandable intraluminal vascular graft of claim 13, wherein the plurality of elongate members are a plurality of wires, and the wires are fixedly secured to one another where the wires intersect with one another.

15. The expandable intraluminal vascular graft of claim 14, wherein the plurality of elongate members are a plurality of tantalum wires.

16. The expandable intraluminal vascular graft of claim 13 wherein the plurality of elongate members are a plurality of thin bars which are fixedly secured to one another where the bars intersect with one another.

17. The expandable intraluminal vascular graft of claim 16, wherein the plurality of elongate members are a plurality of thin tantalum bars.

18. An expandable prosthesis for a body passageway, comprising:

a tubular shaped member having first and second ends and a wall surface disposed between the first and second ends, the wall surface being formed by a plurality of intersecting elongate members, at least some of the elongate members intersecting with one another intermediate the first and second ends of the tubular shaped member;

the tubular shaped member having a first diameter which permits intraluminal delivery of the tubular shaped member into a body passageway having a lumen; and

the tubular shaped member having a second, expanded diameter, upon the application from the interior of the tubular shaped member of a radially, outwardly extending force, which second diameter is variable and controlled by the amount of force applied to the tubular shaped member, at least some of the elongate members being deformed by the radially, outwardly extending force, to retain the tubular shaped member with the second, expanded diameter, whereby the tubular shaped member may be expanded to expand the lumen of the body passageway and remain therein.

19. The expandable prosthesis for a body passageway of claim 18, wherein the plurality of elongate members are a plurality of wires and the wires are fixedly secured to one another where the wires intersect with one another.

20. The expandable prosthesis of claim 19, wherein the plurality of elongate members are a plurality of tantalum wires.

21. The expandable prosthesis for a body passageway of claim 18, wherein the plurality of elongate members are a plurality of thin bars which are fixedly secured to one another where the bars intersect with one another.

22. The expandable prosthesis of claim 21, wherein the plurality of elongate members are a plurality of thin tantalum bars.

23. An apparatus for intraluminally reinforcing a body passageway, comprising:

an expandable, tubular shaped prosthesis having first and second ends, and a wall surface disposed between the first and second ends, the wall surface being formed by a plurality of intersecting elongate members, the expansion of the prosthesis being controllable; and

a catheter, having an expandable, inflatable portion associated therewith and including means for mounting and retaining the expandable, tubular shaped prosthesis on the expandable, inflatable portion,

whereby upon inflation of the expandable, inflatable portion of the catheter, the prosthesis is forced radially outwardly into contact with the body passageway to remain therein, and the expansion of the prosthesis is controlled by the expansion of the inflatable portion of the catheter.

24. The apparatus of claim 23, wherein the plurality of intersecting elongate members are a plurality of intersecting elongate, tantalum members.

25. The apparatus of claim 23, wherein the mounting and retaining means comprises retainer ring members disposed on the catheter adjacent the expandable, inflatable portion and adjacent each end of the expandable, tubular shaped prosthesis.

26. An apparatus for expanding the lumen of a body passageway comprising:

an expandable intraluminal vascular graft having first and second ends, and a wall surface disposed between the first and second ends, the wall surface being formed by a plurality of intersecting elongate members, the expansion of the vascular graft being controllable; and

a catheter, having an expandable, inflatable portion associated therewith and including means for mounting and retaining the expandable intraluminal vascular graft on the expandable, inflatable portion

whereby upon inflation of the expandable, inflatable portion of the catheter, the intraluminal vascular graft is forced radially outwardly into contact with the body passageway to remain therein, and the expansion of the vascular graft is controlled by the expansion of the inflatable portion of the catheter.

27. The apparatus of claim 26, wherein the plurality of intersecting elongate members are a plurality of intersecting elongate, tantalum members.

28. The apparatus of claim 26, wherein the mounting and retaining means comprises retainer ring members disposed on the catheter adjacent the expandable, inflatable portion and adjacent each end of the expandable intraluminal vascular graft.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE EXTENDING PATENT TERM UNDER 35 U.S.C. § 156

PATENT NO.:	4,733,665
DATED:	March 29, 1988
INVENTOR:	Julio C. Palmaz
PATENT OWNER:	Expandable Grafts Partnership

This is to certify that there has been presented to the

COMMISSIONER OF PATENTS AND TRADEMARKS

an application under 35 U.S.C. § 156 for an extension of the patent term. Since it appears that the requirements of the law have been met, this certificate extends the term of the patent for the period of

182 DAYS

with all rights pertaining thereto as provided by 35 U.S.C. § 156(b).

I have caused the seal of the Patent and Trademark Office to be affixed this 20th day of May 1993.

Michael K. Kirk

Michael K. Kirk
Acting Commissioner of Patents and Trademarks

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : B1-4,733,665
DATED : January 11, 1994
INVENTOR(S) : Julio C. Palmaz

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

Column 2

In Claim 29, Line 2, delete "cather", and insert--catheter--

In Claim 29, Line 2, delete "catheri-", and insert--catheteri--.

In Claim 30, Line 3, delete "catherization", and insert--catheterization--.

Signed and Sealed this
Sixth Day of December, 1994

Attest:

Attesting Officer

BRUCE LEHMAN
Commissioner of Patents and Trademarks

US004733665B1

REEXAMINATION CERTIFICATE (2182nd)

United States Patent [19]

Palmaz

[11] B1 4,733,665

[45] Certificate Issued Jan. 11, 1994

[54] **EXPANDABLE INTRALUMINAL GRAFT, AND METHOD AND APPARATUS FOR IMPLANTING AN EXPANDABLE INTRALUMINAL GRAFT**

[75] Inventor: **Julio C. Palmaz**, San Antonio, Tex.

[73] Assignee: **Expandable Grafts Partnership**, Antonio, Tex.

Reexamination Requests:
No. 90/002,493, Oct. 23, 1991
No. 90/002,638, Feb. 12, 1992

Reexamination Certificate for:

Patent No.:	**4,733,665**
Issued:	**Mar. 29, 1988**
Appl. No.:	**796,009**
Filed:	**Nov. 7, 1985**

[51] **Int. Cl.**[5] **A61M 29/00**
[52] **U.S. Cl.** **606/108**; 606/191; 604/96; 604/104; 623/1
[58] **Field of Search** 606/108, 191, 198

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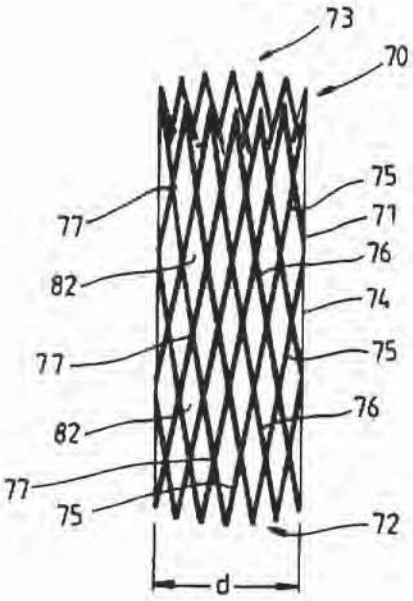
Primary Examiner—Michael H. Thaler

[57] **ABSTRACT**

An expandable intraluminal vascular graft is expanded within a blood vessel by an angioplasty balloon associated with a catheter to dilate and expand the lumen of a blood vessel. The graft may be a wire mesh tube.



REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307

THE PATENT IS HEREBY AMENDED AS INDICATED BELOW.

Matter enclosed in heavy brackets [ ] appeared in the patent, but has been deleted and is no longer a part of the patent; matter printed in italics indicates additions made to the patent.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

The patentability of claims **23–28** is confirmed.

Claims **1, 7, 13** and **18** are determined to be patentable as amended.

Claims **2–6, 8–12, 14–17** and **19–22**, dependent on an amended claim, are determined to be patentable.

New claims **29–32** are added and determined to be patentable.

1. A method for implanting a prosthesis *at a desired location* within a body passageway comprising the steps of:

disposing the prosthesis upon a catheter;

inserting the prosthesis and catheter within the body passageway by catheterization of said body passageway; [and]

delivering the catheter and prosthesis through the body passageway to the desired location in the body passageway without surgically exposing the desired location of the body passageway; and

providing controllable expansion of the prosthesis at [a] *the* desired location within the body passageway by expanding a portion of the catheter associated with the prosthesis to force the prosthesis radially outwardly into contact with the body passageway, by deforming a portion of the prosthesis with a force in excess of the elastic limit of the portion of the prosthesis, to implant the prosthesis within the body passageway.

7. A method for expanding the lumen of a body passageway comprising the steps of:

[inserting an intraluminal graft, disposed upon a catheter, into the body passageway until it is disposed adjacent a desired location within the body passageway; and]

disposing an intraluminal graft upon a catheter;

inserting the intraluminal graft and catheter within the body passageway by catheterization of the body passageway;

delivering the intraluminal graft and catheter through the body passageway to a desired location within the body passageway without surgically exposing the desired location of the body passageway; and

expanding a portion of the catheter to provide controllable expansion of the intraluminal graft radially, outwardly into contact with the body passageway, by deforming a portion of the intraluminal graft with a force in excess of the elastic limit of the portion of the [prosthesis] *intraluminal graft*, until the lumen of the body passageway at the desired location in the body passageway has been expanded, whereby the intraluminal graft prevents the body passageway from collapsing and decreasing the size of the expanded lumen, and the intraluminal graft remains in the *body* passageway.

13. An expandable intraluminal vascular graft, comprising:

a tubular shaped member having first and second ends and a *smooth outer* wall surface, *without any narrow, outwardly projecting edges,* disposed between the first and second ends, the wall surface being formed by a plurality of intersecting elongate members, at least some of the elongate members intersecting with one another intermediate the first and second ends of the tubular shaped member;

the tubular shaped member having a first diameter which permits intraluminal delivery of the tubular shaped member into a body passageway having a lumen; and

the tubular shaped member having a second, expanded diameter *and a substantially smooth outer wall surface, without any narrow, outwardly projecting edges,* upon the application from the interior of the tubular shaped member of a radially, outwardly extending force, which second diameter is variable and controlled by the amount of force applied to the tubular shaped member, at least some of the elongate members being deformed by the radially, outwardly extending force to retain the tubular shaped member with the second, expanded diameter, whereby the tubular shaped member may be expanded to expand the lumen of the body passageway and remain therein.

18. An expandable prosthesis for a body passageway, comprising:

a tubular shaped member having first and second ends and a *smooth outer* wall surface, *without any narrow, outwardly projecting edges,* disposed between the first and second ends, the wall surface being formed by a plurality of intersecting elongate members, at least some of the elongate members intersecting with one another intermediate the first and second ends of the tubular shaped member;

the tubular shaped member having a first diameter which permits intraluminal delivery of the tubular shaped member into a body passageway having a lumen; and

the tubular shaped member having a second, expanded diameter *and a substantially smooth outer wall surface, without any narrow outwardly projecting edges,* upon the application from the interior of the tubular shaped member of a radially, outwardly extending force, which second diameter is variable and controlled by the amount of force applied to the tubular shaped member, at least some of the elongate members being deformed by the radially, outwardly extending force, to retain the tubular shaped member with the second, expanded diameter, whereby the tubular shaped member may be expanded to expand the lumen of the body passageway and remain therein.

29. The method of claim 1, wherein the prosthesis and cather are inserted within the body passageway by catherization through a body orifice.

30. The method of claim 1, wherein the prosthesis and catheter are inserted within the body passageway by percutaneous catherization of the body passageway.

31. The method of claim 7, wherein the intraluminal graft and catheter are inserted within the body passageway by catheterization through a body orifice.

32. The method of claim 7, wherein the intraluminal graft and catheter are inserted within the body passageway by percutaneous catheterization of the body passageway.

* * * * *

US004733665C2

(12) **REEXAMINATION CERTIFICATE** (4528th)

United States Patent
Palmaz

(10) **Number: US 4,733,665 C2**
(45) **Certificate Issued: Jan. 29, 2002**

(54) **EXPANDABLE INTRALUMINAL GRAFT, AND METHOD AND APPARATUS FOR IMPLANTING AN EXPANDABLE INTRALUMINAL GRAFT**

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(73) Assignee: **Expandable Grafts Partnership**, San Antonio, TX (US)

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(52) **U.S. Cl.** **606/108**; 604/104; 604/96.01; 623/1.11; 623/1.15
(58) **Field of Search** 623/1.11, 1.15

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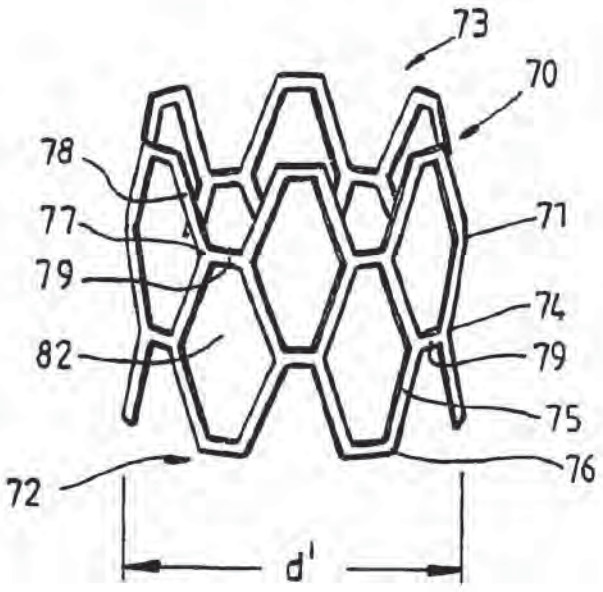
Primary Examiner—Michael H. Thaler

(57) **ABSTRACT**

An expandable intraluminal vascular graft is expanded within a blood vessel by an angioplasty balloon associated with a catheter to dilate and expand the lumen of a blood vessel. The graft may be a wire mesh tube.



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REEXAMINATION CERTIFICATE ISSUED UNDER 35 U.S.C. 307

THE PATENT IS HEREBY AMENDED AS INDICATED BELOW.

Matter enclosed in heavy brackets [ ] appeared in the patent, but has been deleted and is no longer a part of the patent; matter printed in italics indicates additions made to the patent.

AS A RESULT OF REEXAMINATION, IT HAS BEEN DETERMINED THAT:

The patentability of claims **13–28** is confirmed.

Claims **1** and **7** are determined to be patentable as amended.

Claims **2–6**, **8–12** and **29–32**, dependent on an amended claim, are determined to be patentable.

New claims **33** and **34** are added and determined to be patentable.

1. A method for implanting a prosthesis at a desired location within a body passageway comprising the steps of:

disposing the prosthesis upon a catheter;

inserting the prosthesis and catheter within the body passageway by catheterization of said body passageway;

delivering the catheter and prosthesis through the body passageway to the desired location in the body passageway without surgically exposing the desired location of the body passageway, *wherein the desired location in the body passageway is the location of an existing natural obstruction*; and

providing controllable expansion of the prosthesis at the desired location within the body passageway by expanding a portion of the catheter associated with the prosthesis to force the prosthesis radially outwardly into contact with the body passageway, by deforming a portion of the prosthesis with a force in excess of the elastic limit of the portion of the prosthesis, to implant the prosthesis within the body passageway.

7. A method for expanding the lumen of a body passageway comprising the steps of:

diposing an intraluminal graft upon a catheter;

inserting the intraluminal graft and catheter within the body passageway by catheterization of the body passageway;

delivering the intraluminal graft and catheter through the body passageway to a desired location within the body passageway without surgically exposing the desired location of the body passageway, *wherein the desired location in the body passageway is the location of an existing natural obstruction*; and

expanding a portion of the catheter to provide controllable expansion of the intraluminal graft radially, outwardly into contact with the body passageway, by deforming a portion of the intraluminal graft with a force in excess of the elastic limit of the portion of the intraluminal graft, until the lumen of the body passageway at the desired location in the body passageway has been expanded, whereby the intraluminal graft prevents the body passageway from collapsing and decreasing the size of the expanded lumen, and the intraluminal graft remains in the body passageway.

33. A method for implanting a balloon expandable stent prosthesis within a passageway of a coronary artery having an area of stenosis, comprising the steps of:

disposing the stent prosthesis upon a catheter having an inflatable balloon portion,

inserting the stent prosthesis and catheter within the body passageway by percutaneous catherization,

delivering the catheter and stent prosthesis through the body passageway to the area of stenosis without surgically exposing the area of the body passageway; and

providing controllable expansion of the stent prosthesis at the area of stenosis within the coronary artery passageway by expanding a portion of the inflatable balloon portion of the catheter associated with the stent prosthesis to force the stent prosthesis radially outwardly into contact with the area of stenosis in the body passageway, by deforming a portion of the stent prosthesis with a force in excess of the elastic limit of the portion of the stent prosthesis to implant the stent prosthesis within the body passageway at the area of stenosis.

34. In combination, a balloon expandable stent prosthesis for implantation in the passageway of a coronary artery having an area of stenosis and a catheter, comprising:

an expandable stent prosthesis being a tubular shaped member having first and second ends and a smooth outer wall surface without any narrow, outwardly projecting edges, disposed between the first and second ends, the wall surface being formed by a plurality of intersecting elongate members, at least some of the elongate members intersecting with one another intermediate the first and second ends of the tubular shaped member;

a catheter having an expandable, inflatable balloon portion;

the tubular member being disposed on the balloon portion of the catheter,

the tubular shaped member having a first diameter which permits intraluminal delivery of the tubular shaped member and the catheter into a lumen of a coronary artery having an area of stenosis;

the tubular shaped member having a second, expanded diameter and a substantially smooth outer wall surface without any narrow outwardly projecting edges, upon the application from the interior of the tubular shaped member of a radially, outwardly extending force, which second diameter is variable and controlled by the amount of force applied to the tubular shaped member, at least some of the elongate members being deformed by the radially, outwardly extending force, to retain the tubular shaped member with the second, expanded diameter, whereby the tubular shaped member may be expanded to expand the coronary artery in the area of stenosis.

* * * * *

EXHIBIT 87

US005703876A

United States Patent [19]

Christie

[11] Patent Number: 5,703,876

[45] Date of Patent: Dec. 30, 1997

[54] **ATM TRANSPORT SYSTEM**

[76] Inventor: **Joseph Michael Christie**, 536 Green Ave., San Bruno, Calif. 94066

[21] Appl. No.: **562,206**

[22] Filed: **Nov. 22, 1995**

[51] **Int. Cl.**[6] **H04L 12/66**

[52] **U.S. Cl.** **370/395**; 370/410; 370/466; 370/524

[58] **Field of Search** 370/60, 60.1, 79, 370/80, 94.2, 99, 110.1, 356, 395, 397, 399, 409, 410, 426, 466, 467, 524

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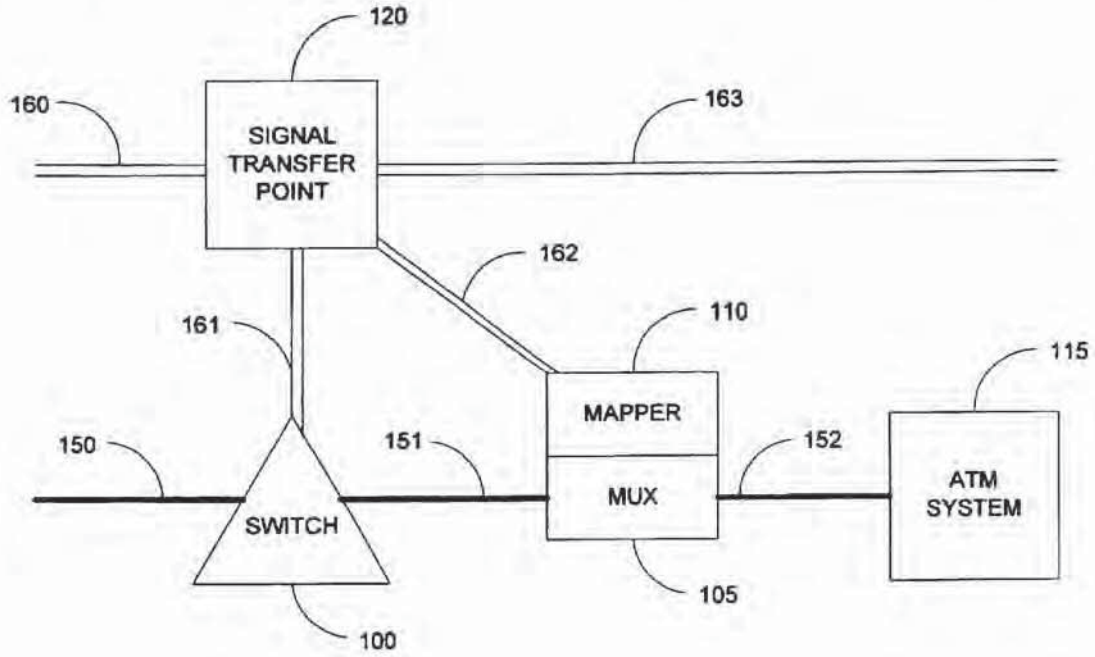
Primary Examiner—Douglas W. Olms
Assistant Examiner—Min Jung
Attorney, Agent, or Firm—Harley R. Ball; Michael J. Setter

[57] **ABSTRACT**

The invention is an ATM transport system that transports user information from a continuous signal transport system. The ATM transport system uses telecommunications signaling associated with the continuous signals to determine if the continuous signals are transporting any user information. If so, ATM cells containing user information are generated and transmitted, but if not ATM cells are not generated and transmitted. The invention includes an ATM interworking multiplexer and in some embodiments, a processor.

14 Claims, 2 Drawing Sheets



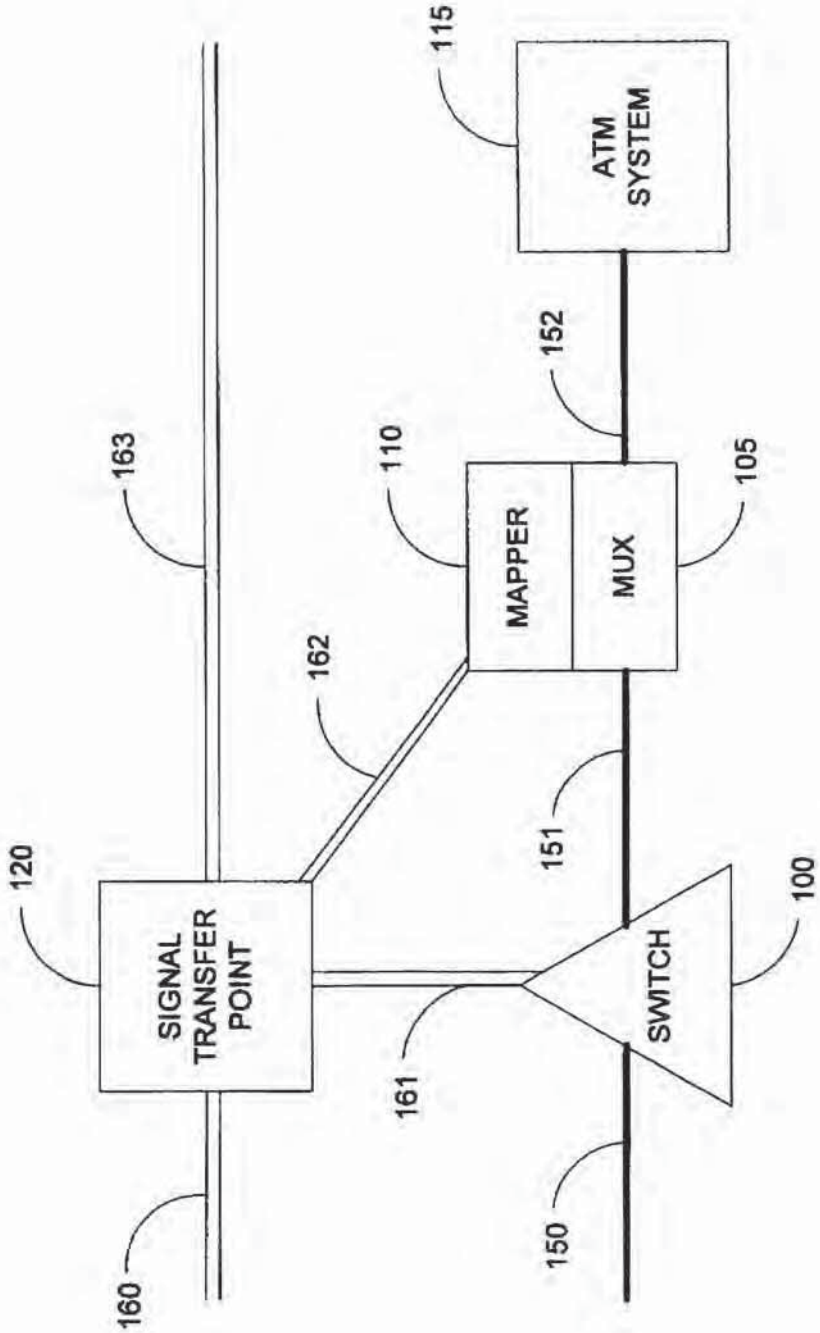

115
ATM SYSTEM
152
163
110
MAPPER
MUX
105
162
151
120
SIGNAL TRANSFER POINT
SWITCH
100
161
150
160

FIGURE 1

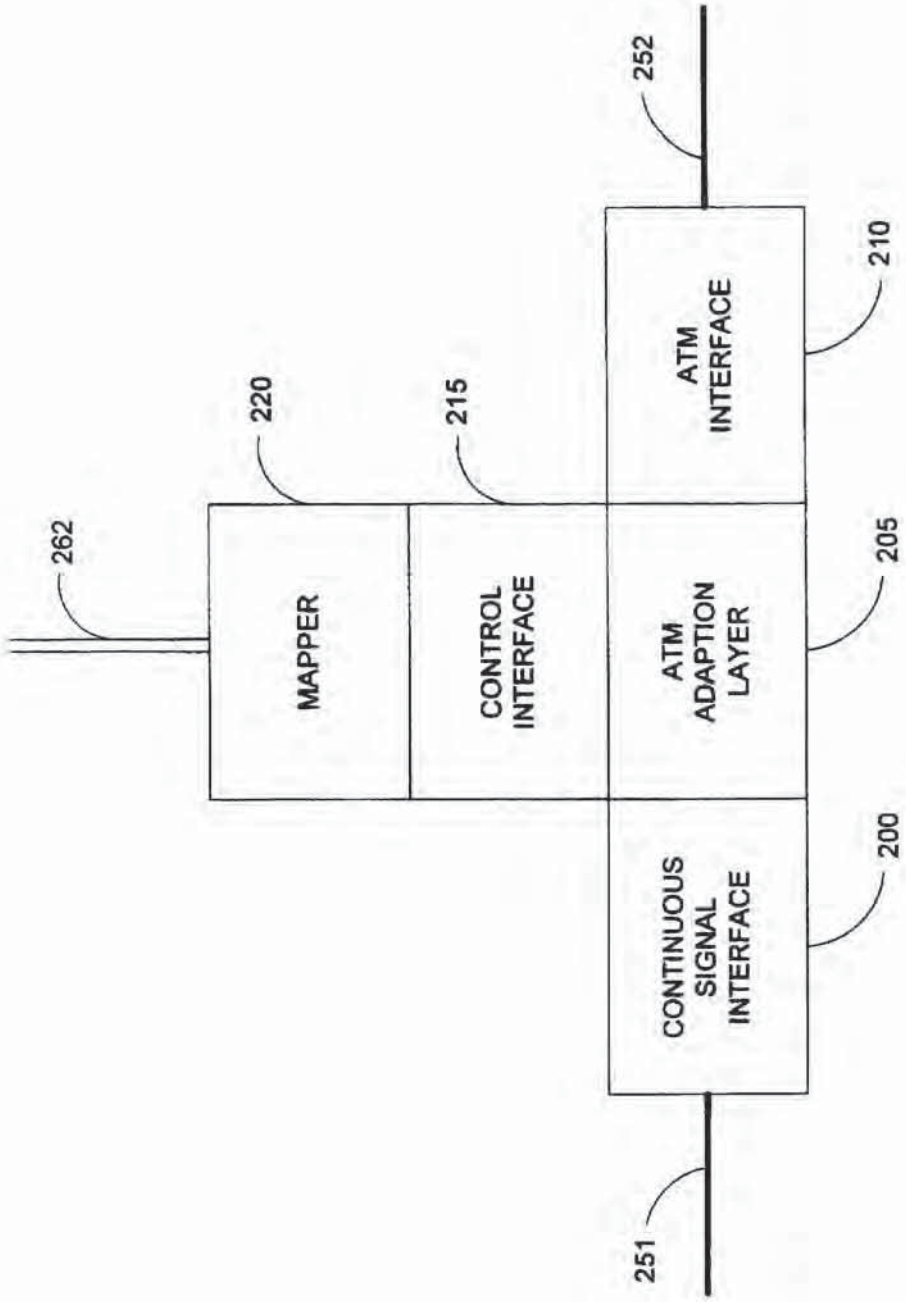

252
210
ATM INTERFACE
220
215
262
MAPPER
CONTROL INTERFACE
ATM ADAPTION LAYER
205
200
CONTINUOUS SIGNAL INTERFACE
251

FIGURE 2

ATM TRANSPORT SYSTEM

BACKGROUND

At present, Asynchronous Transfer Mode (ATM) technology is being used to provide high speed transport for traffic carried by older transport formats such as DS1 and DS0. This ATM transport technique uses an ATM interworking multiplexer (ATM mux) to convert telecommunications traffic from the older formats into ATM cells that can be transported over broadband connections. At the terminating end of the broadband system, the ATM cells are re-converted back into the older format by another ATM mux for delivery to the older transport system.

Many older transport formats require the transmission of a continuous signal even when no user traffic is being transported. For example, a DS0 connection continuously transmits a 64,000 bit/second signal whether or not the DS0 connection is transporting any user traffic. This causes a problem in the above-described transport scenario. The ATM mux will convert the DS0 signal into ATM cells for transport, and since the DS0 signal is continuous, a continuous stream of ATM cells must be transported by the ATM network. This occurs even when no user traffic is being transported. The idle DS0 signal is still transported in empty ATM cells. Methods to detect these idle continuous signals that do not transport user information have included analyzing information samples from the continuous signals to detect idle codes. However, these idle codes may be emulated by user information such as voice or data. This causes problems when trying to determine whether or not a signal carries user information.

The current situation represents a waste of resources. At present, there is a need for an ATM system that can transport continuous signal formats when they carry user traffic, but not when they do not carry user traffic.

SUMMARY

The invention includes an asynchronous transfer mode (ATM) system for transporting user information in ATM cells. The ATM cells contain a virtual path identification/virtual channel identification (VPI/VCI). The user information is from a continuous-signal transport system that produces telecommunications signaling related to the continuous signal. The continuous signal is associated with the VPI/VCI.

The system comprises a processor and ATM interworking multiplexer. The processor receives telecommunications signaling and detects, based on the telecommunications signaling, when the continuous signal is transporting user information and when the continuous signal is not transporting user information. The processor associates the continuous signal with the VPI/VCI. The processor also provides a control instruction to enable the VPI/VCI when the continuous signal is transporting user information, and provides a control instruction to disable the VPI/VCI when the continuous signal is not transporting user information.

The ATM interworking multiplexer is coupled to the processor. The ATM interworking multiplexer receives the continuous signal and associates it with the VPI/VCI. The ATM interworking multiplexer receives the control instructions from the processor and generates and transmits ATM cells containing the VPI/VCI and the user information in response to the enabling control instruction. The ATM interworking multiplexer stops generating and transmitting ATM cells containing the VPI/VCI in response to the disabling control instruction.

The invention has many variations. The telecommunications signaling protocol could be Signaling System #7. The processor might use an SS7 Initial Address Message (IAM) to detect when the continuous signal transports user information. The processor might use a Circuit Identification Code (CIC) in the SS7 IAM to identify the continuous signal and to associate the continuous signal with the VPI/VCI. The processor might use a an SS7 Release message (REL) or Release Complete message (RLC) to detect when the continuous signal no longer transports user information.

The invention might include a Signal Transfer Point (STP) that is linked to the processor and that transfers telecommunications signaling to the processor. The STP might transfer copies of Signaling System #7 (SS7) message routing labels to the processor. The STP might transfer copies of SS7 Initial Address Message (IAM), Release message (REL), or Release Complete message (RLC) routing labels to the processor. The STP might transfer copies of SS7 routing labels to the processor that have particular Originating Point Codes (OPCs) and Destination Point Codes (DPCs).

The ATM interworking multiplexer might receive a continuous DS3 signal or a continuous DS1 signal. The ATM interworking multiplexer might transmit the ATM cells over a SONET connection. In some embodiments, the ATM interworking multiplexer supports multiple signals. Individual VPI/VCIs would correspond to individual continuous signals. The ATM interworking multiplexer would include: a continuous signal interface to receive the continuous signals, an ATM Adaption Layer (AAL) to convert the continuous signals into ATM cells with corresponding VPI/VCIs, an ATM interface to transmit the ATM cells, and a control interface to receive the control instructions and control the AAL to generate and transmit cells with enabled VPI/VCIs and to stop the generation and transmission of ATM cells with a disabled VPI/VCIs.

The invention provides the advantage of having the ATM system only transport cells that actually carry user information. Cells containing the continuous signal, but no user information are not transmitted. This provides for efficient allocation and use of bandwidth in the ATM system.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a version of the present invention.

FIG. 2 is a block diagram of a version of the present invention.

DETAILED DESCRIPTION

For purposes of clarity, the term "connection" will be used to refer to the transmission media used to carry user traffic. The term "link" will be used to refer to the transmission media used to carry signaling. On the Figures, connections are shown by a single line and signaling links are shown by double lines.

FIG. **1** depicts a version of the present invention. Shown are switch **100**, ATM interworking multiplexer (mux) **105**, mapper **110**, ATM system **115**, and signal transfer point (STP) **120**. These components are connected by connections **150–152** and linked by links **160–163** as shown. Those skilled in the art are aware that large networks have many more components than are shown, but the number of these components has been restricted for clarity. The invention is fully applicable to a large network.

Switch **100** is a conventional switch that transmits user traffic within continuous signals. Examples of continuous

signals are DS3, DS1, or DS0 signals. Connections **150** and **151** are conventional transmission media that propagate continuous signals in order to transport user information. ATM system **115** and connection **152** are conventional components that transport ATM cells. The components mentioned in this paragraph are well known in the art.

Telecommunications signaling is used to set-up and tear down connections for a call. STP **120** routes the signaling over signaling links **160–163**. The invention is described in terms of signaling system #7 (SS7), but those skilled in the art are aware of other signaling systems that could also be used with the invention. Signaling links **160–163** could be well known SS7 links. STP **120** is a signaling device, for example, it could be a conventional STP that has been altered in accord with the invention. In other embodiments described later, no alteration of the STP would be required.

In this embodiment, STP **120** is altered to copy the routing labels of particular SS7 messages and transmit them to mapper **110** over link **162**. The routing label of an SS7 message carries routing information for the signaling message such as the origination point code (OPC) and destination point code (DPC) of the message. The routing label contains a circuit identification code (CIC) and a message type. The CIC identifies the actual circuit that carries the user traffic on a given call. Typically, the CIC identifies a DS0 connection. The message type identifies the type of message. In SS7, the initial address message (IAM) is used to set-up the call, and the release message (REL) and/or the release complete message (RLC) is used to tear down the call. Typically, an REL causes a call connection to be released and the RLC is an acknowledgment of the release. But occasionally, the REL is not received and the RLC actually causes the release of a call connection.

Mapper **110** would only need the IAMs, and RELs for calls that use connection **151**. To get a more robust system, the RLCs could also be used. The RLC would act as an acknowledgment when the REL is received, but would be used to for tear down when no REL is received. Alternatively, the use of the RLC could be omitted if the unreceived REL messages still allowed for tolerable performance.

Those skilled in the art will be familiar with various ways to select these routing labels. A discrimination function could select the proper messages based on the message type, the OPC, and/or the DPC. For example, messages type would be screened for IAM, REL, or RLC codes. These messages would then be screened for the OPC or DPC of switch **100**. Additional screening criteria will be appreciated by those skilled in the art. The discrimination function could be in STP **120**, in mapper **110**, or distributed in between the two. For example, STP **110** could send only IAM, REL, and RLC routing labels to mapper **110**, and mapper **110** would only use routing labels that had an OPC/DPC combination associated with connection **151**.

Mapper **110** would typically be a processor that has conventional interface software that is functional to receive and process the routing labels provided by STP **120**; however, other processing configurations that support the requirements of the invention are also contemplated. In addition, mapper **110** would be functional to use the OPC, DPC, and CIC of the signaling messages to retrieve predefined virtual connection associated with the particular CIC. The virtual connection would be identified by the combination of a virtual path identification (VPI) and virtual channel identification (VCI). ATM VPIs and VCIs are well known. Typically each DS0 on one side of mux **105** would have a corresponding VPI/VCI on the other.

In addition, mapper **110** would be functional to send control messages to mux **105**. For call-set up, the control message would instruct mux **105** to enable the VPI/VCI associated with the call. For call tear down, the control message would instruct mux **105** to disable the VPI/VCI associated with call

Mux **105** would be configured to interwork the DS0s on connection **151** with their corresponding VPI/VCIs on connection **152**. Mux **105** would convert user traffic from the DS0 into ATM cells that identify the corresponding VPI/VCI. Mux **105** would then transmit the ATM cells over connection **152** to ATM system **120**. Mux **105** is also functional to perform reciprocal processing for ATM cells from connection **152** that contain user information that is bound for transport over connection **151**. Mux **105** would be functional to enable and disable VPI/VCIs as instructed by the control messages from mapper **110**. This means that ATM cells would only be transmitted over an enabled VPI/VCI. If the VPI/VCI is disabled, mux **105** would not transmit cells on that virtual connection.

In one embodiment, the system would operate as follows for a call incoming over connection **150**. A DS0 on connection **150** would be seized for a call connection to switch **100**. An IAM would be received over link **160** and routed by STP **120** over link **161** to switch **100**. Switch **100** would process the IAM and select a DS0 on connection **151**. Switch **100** would generate another IAM for transfer to the network over link **161** and STP **120**.

STP **120** would check the message type, OPC, and DPC to determine that this was an IAM from switch **100** concerning connection **151**. As a result STP **120** would copy the routing label of the IAM and transfer it to mapper **115** over link **162**. Mapper **115** would identify the VPI/VCI that corresponds to the OPC/DPC/CIC in the IAM. Mapper **110** would then send a control message to mux **105** instructing mux **105** to enable the VPI/VCI. Once the VPI/VCI was enabled, mux **105** would begin to transmit ATM cells using the VPI/VCI over connection **152** to ATM system **115**. The cells would contain information from the DS0 on connection **151** identified by the IAM routing label.

When the call is terminated, an REL would be transmitted over the signaling system to switch **100**. STP **120** would check the message type and the DPC to determine that this was an REL to switch **100** concerning connection **151**. As a result, STP **120** would copy the routing label of the REL and transfer it to mapper **110** over link **162**. Mapper **110** would identify the VPI/VCI that corresponded to the OPC/DPC/CIC in the REL. Mapper **110** would then send a control message to mux **105** instructing it to disable the VPI/VCI. As a result, mux **105** would not transmit cells over the disabled VPI/VCI. If RLCs are used, they would act as an acknowledgment for the REL, and if the REL was not received, then the RLC would be used in the same way the REL is used above.

A similar procedure would occur for calls that are set-up from the opposite direction—from ATM system **115** to connection **150**. In this case, VCI/VPIs would be enabled/disabled based on the IAMs and RELs (and possibly RLCs) that are related to connection **151**.

The invention has a significant advantage because virtual connections are only used when they are needed during a call and are disabled when the call is over. This prevents the mux from transmitting empty cells that do not contain any user traffic. This allows for a more efficient allocation and use of bandwidth in the ATM network.

FIG. **2** shows a more detailed version of the mux and the mapper. Shown are continuous signal interface **200**, ATM

adaption layer (AAL) **205**, ATM interface **210**, control interface **215**, and mapper **220**. Also shown are continuous signal connection **251**, ATM connection **252** and signaling link **262**.

Continuous signal connection **251** transports user traffic using continuous signals with an example being DS3 signals. ATM connection **252** transports ATM cells with one example being a SONET connection. An example of signaling link **262** would be an SS7 link. Continuous signal interface **200** is operable to receive user information in continuous signal formats, such as the DS3 format. Signals such as DS3 and DS1 are typically demuxed into component DS0 signals by continuous signal interface **200**.

AAL **205** comprises both a convergence sublayer and a segmentation and reassembly (SAR) layer. AAL **205** is operational to accept the user information from continuous signal interface **200** and convert the information into ATM cells. AAL **205** would select the VPI/VCI for the ATM cells based the particular incoming connection. For example, a particular incoming DS0 would use a pre-assigned VPI/VCI. AALs are known in the art and information about AALs is provided by International Telecommunications Union (ITU) document 1.363.1. An AAL for voice is also described in U.S. Pat. No. 5,606,553, filed on Feb. 28, 1995, entitled "Cell Processing for Voice Transmission", and hereby incorporated by reference into this application. ATM interface **210** is operational to accept ATM cells and transmit them over ATM connection **252**

Control interface **215** is functional to accept control messages from mapper **220** and cause particular VPI/VCIs to be enabled/disabled. This could be done by having AAL **205** verify that the VPI/VCI is enabled before generating cells. This could also be done by having ATM interface **210** screen out ATM cells with a disabled VPI/VCI. Those skilled in the art will appreciate various ways to suppress cell transmission over disabled VPI/VCIs.

Mapper **220** is functional to accept routing labels from signaling link **262** and determine if a VPI/VCI should be enabled or disabled. Mapper **220** would require interface software to operate over link **162** and to communicate with control interface **215**. Mapper **220** may have discrimination logic to select appropriate routing labels for further processing. These elements have been discussed above.

The system operates as follows. Signaling message routing labels arrive on link **262** and are processed by mapper **220**. As discussed, this may require some discrimination to determine if the routing label should be processed by mapper **220**. Only routing labels associated with the set-up and tear down of calls using connection **251** need to be processed.

Mapper **220** would determine the affected VPI/VCI using the OPC, DPC, and CIC. If the message type was for an IAM, an enable VPI/VCI control message would be sent to control interface **215**. If the message type was for an REL (or possibly an RLC), a disable VPI/VCI control message would be sent to control interface **215**. In this way, ATM cells would only be transmitted during the actual call. When the call is terminated, the VPI/VCI is disabled so that empty cells are not transmitted. When another call requires the VPI/VCI, it would be enabled allowing cell transmission. This saves significant bandwidth over prior systems that transmitted cells regardless of whether or not an actual call required the connection.

Those skilled in the art will appreciate variations of the above described embodiment. In some embodiments, other signaling, such as C7 or UNI signaling could be used instead of SS7. In some embodiments, the location of message discrimination might be in the mapper, or in the STP, or distributed in both. In some embodiments, the switch could be programmed to forward copies of the appropriate routing labels to the mapper. A conventional STP could be used in this case. In some embodiments, the actual messages may be passed through the mapper so that no copies need to be made. The mapper would passively read the pertinent information. In some embodiments, the mapper function could reside at the switch, the STP, or independently of other components. In these cases, the mapper would communicate with the mux over a conventional control channel. Also, multiple mappers could be used or a single mapper could be used to control multiple muxes. In addition to these embodiments, other variations will be appreciated by those skilled in the art. As such, the scope of the invention is not limited to the specified embodiments, but is only restricted to the following claims.

I claim:

1. An asynchronous transfer mode (ATM) system for transporting user information in ATM cells that contain a virtual path identification/virtual channel identification (VPI/VCI), wherein the user information is from a continuous-signal transport system that uses a continuous signal to transport the user information and that produces Signaling System #7 (SS7) signaling related to the continuous signal, and wherein the continuous signal is associated with the VPI/VCI, the system comprises;

a processor that is operational to receive the SS7 signaling and detect when the continuous signal transports user information based on at least a portion of an SS7 Initial Address Message (IAM), wherein the processor is operational to use a Circuit Identification Code (CIC) in the SS7 IAM to identify the continuous signal and to associate the continuous signal with the VPI/VCI, wherein the processor is operational to provide a control instruction to enable the VPI/VCI when the continuous signal is transporting the user information, wherein the processor is operational to detect when the continuous signal is not transporting the user information, and wherein the processor is operational to provide a control instruction to disable the VPI/VCI when the continuous signal is not transporting the user information; and

an ATM interworking multiplexer connected to the continuous signal transport system and coupled to the processor, wherein the ATM interworking multiplexer is operational to receive the continuous signal from the continuous signal transport system, to associate the continuous signal with the VPI/VCI, to receive the control instructions from the processor, to generate and transmit ATM cells containing the VPI/VCI and the user information in response to the enabling control instruction, and to stop generating and transmitting ATM cells containing the VPI/VCI in response to the disabling control instruction.

2. The system of claim **1** wherein the processor is operational to use at least a portion of an SS7 Release message (REL) to detect when the continuous signal no longer transports user information.

3. The system of claim **1** wherein the processor is operational to use at least a portion of an SS7 Release Complete message (RLC) to detect when the continuous signal no longer transports user information.

4. The system of claim **1** further comprising a Signal Transfer Point (STP) that is linked to the processor and is operational to transfer the SS7 signaling to the processor.

5. The system of claim 4 wherein the STP is operational to transfer copies of SS7 message routing labels to the processor.

6. The system of claim 4 wherein the STP is operational to transfer copies of SS7 IAM and Release message (REL) routing labels to the processor.

7. The system of claim 4 wherein the STP is operational to transfer copies of SS7 Release Complete message (RLC) routing labels to the processor.

8. The system of claim 4 wherein the STP is operational to transfer copies of SS7 routing labels to the processor that have particular Originating Point Codes (OPCs) and Destination Point Codes (DPCs).

9. The system of claim 1 further comprising a switch that is linked to the processor and is operational to transfer the SS7 signaling to the processor, and wherein the switch is connected to the ATM interworking multiplexer and is operational to transmit the continuous signal to the ATM interworking multiplexer.

10. The system of claim 1 wherein the ATM interworking multiplexer is operational to receive a continuous DS3 signal.

11. The system of claim 1 wherein the ATM interworking multiplexer is operational to receive a continuous DS1 signal.

12. The system of claim 1 wherein the ATM interworking multiplexer is functional to transmit the ATM cells over a SONET connection.

13. A method of transporting user information in ATM cells in an asynchronous transfer mode (ATM) system, wherein the ATM cells contain a virtual path identification and a virtual channel identification (VPI/VCI), wherein the user information is from a continuous-signal transport system that uses a continuous signal to transport the user information and that transmits Signaling System #7 (SS7) signaling related to the continuous signal, and wherein the continuous signal corresponds to the VPI/VCI, the method comprising;

receiving the continuous signal and an SS7 Initial Address Message (IAM) from the continuous signal transport system and detecting when the continuous signal is transporting the user information based on the SS7 IAM;

associating the continuous signal with the corresponding VPI/VCI based on a Circuit Identification Code (CIC) in the IAM and in response to detecting that the continuous signal is transporting the user information;

generating and transmitting ATM cells containing the corresponding VPI/VCI and the user information in response to detecting that the continuous signal is transporting the user information and associating the continuous signal with the corresponding VPI/VCI;

receiving an SS7 Release Message (REL) and detecting when the continuous signal is not transporting the user information based on the SS7 REL; and

stopping the generation and transmission of ATM cells containing the corresponding VPI/VCI and the user information in response to detecting that the continuous signal is not transporting the user information.

14. A method of transporting user information in ATM cells in an asynchronous transfer mode (ATM) system, wherein the ATM cells contain a virtual path identification and a virtual channel identification (VPI/VCI), wherein the user information is from a continuous-signal transport system that uses a continuous signal to transport the user information and that transmits Signaling System #7 (SS7) signaling related to the continuous signal, and wherein the continuous signal corresponds to the VPI/VCI, the method comprising;

receiving the continuous signal and an SS7 Initial Address Message (IAM) from the continuous signal transport system and detecting when the continuous signal is transporting the user information based on the SS7 IAM;

associating the continuous signal with the corresponding VPI/VCI based on a Circuit Identification Code (CIC) in the IAM and in response to detecting that the continuous signal is transporting the user information;

generating and transmitting ATM cells containing the corresponding VPI/VCI and the user information in response to detecting that the continuous signal is transporting the user information and associating the continuous signal with the corresponding VPI/VCI;

receiving an SS7 Release Complete message (RLC) and detecting when the continuous signal is not transporting the user information based on the SS7 RLC; and

stopping the generation and transmission of ATM cells containing the corresponding VPI/VCI and the user information in response to detecting that the continuous signal is not transporting the user information.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,703,876
DATED : December 30, 1997
INVENTOR(S) : Joseph Michael Christie

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
Insert Item:

-- **Related U.S. Application Data**

[63] Continuation-in part of application No. 08/525,897, filed on Sep. 8, 1995, now Pat. No. 5,991,301, which is a continuation-in-part of application No. 08/238,605, filed on May 5, 1994, now abandoned. --

Signed and Sealed this

Twenty-seventh Day of April, 2004

JON W. DUDAS
Acting Director of the United States Patent and Trademark Office